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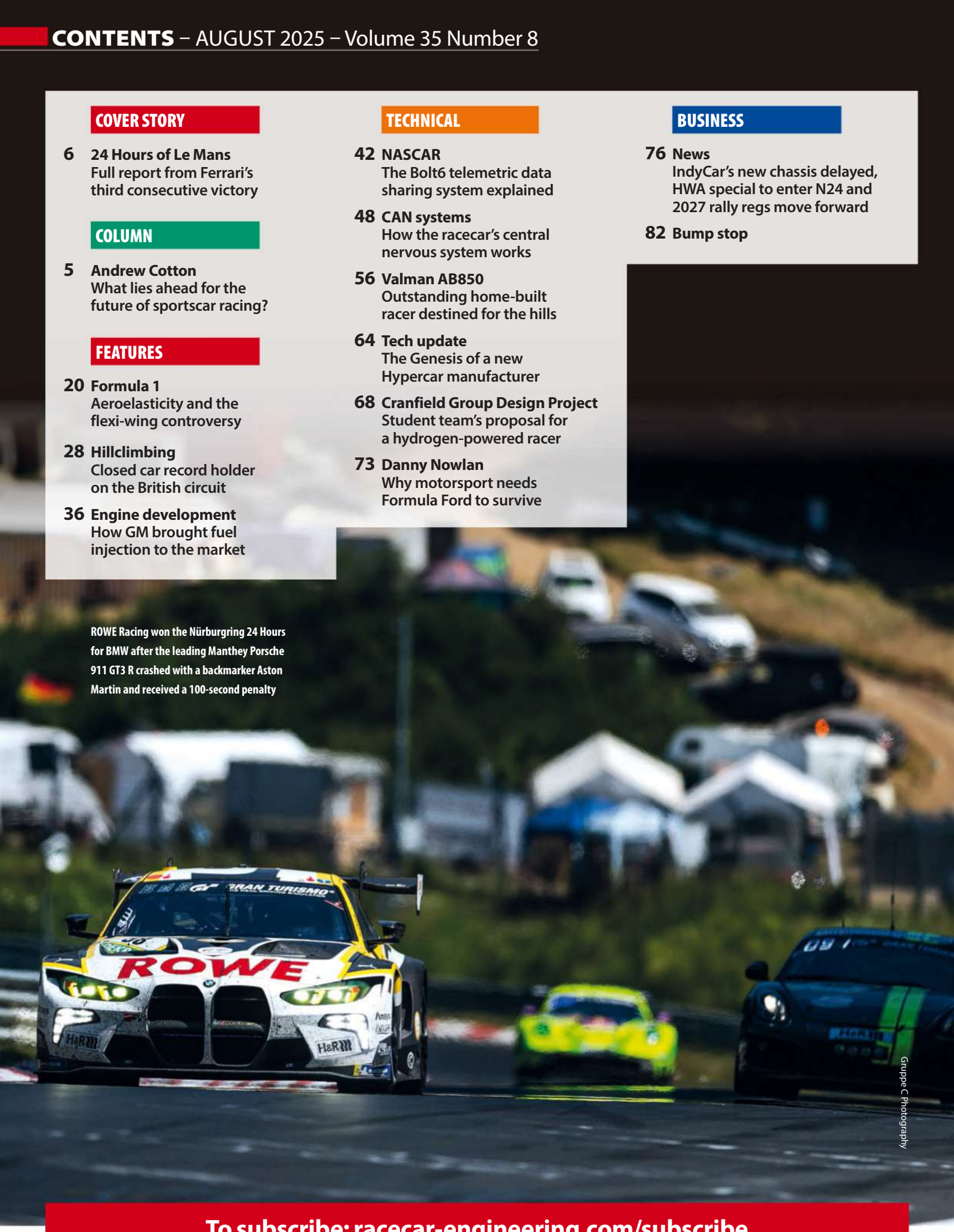

ROWE Racing won the Nürburgring 24 Hours for BMW after the leading Manthey Porsche 911 GT3 R crashed with a backmarker Aston Martin and received a 100-second penalty

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Homologate or regulate?

Trying to make sense of the whirling sportscar paddock rumour mill

The annual press conference at the 24 Hours of Le Mans was only slightly confusing this year. The ACO signed with IMSA a continuation of their transatlantic 'strategic alliance' to 2032. This includes collaboration on the LMDh regulations and the use of European categories like LMP2 and LMP3 in North America. The FIA confirmed an extension of their Hypercar regulations to the same date, but also the homologation cycle.

There is a subtle, but important difference. The homologation cycle means a relationship between promoters continues; the continuation of the regulations means that current LMH and LMDh cars will remain active in the FIA World Endurance Championship for that period. Given what happened at Le Mans, where Ferrari 499Ps quickly moved into the top three positions and then dominated for much of the race, the likelihood of these cars remaining unchanged for a further seven years seems fanciful.

In the process of paddock walking and talking, a number of threads started to come together. Specialist chassis manufacturers, including current licensed LMDh builders, are chasing new business, with one in particular looking at the emerging Chinese market. Another was scouting for a new LMH manufacturer to partner with, and there is a persistent and niggling rumour that one more is coming.

Toyota Gazoo Racing

The Hypercar class will continue until 2032, although by then it is expected that the first hydrogen prototypes will have joined the party

Fuel source

Naturally, hydrogen was a further hot topic in the paddock. Toyota reaffirmed its commitment, presenting a test car running on the FIA's mandated liquid-stored fuel, while the ACO sort of hinted at a date of 2028 for hydrogen arriving on track.

There are, however, a few problems with this plan. One is making the technology in the car fast enough, safe enough and reliable enough over the next three years to actually race it. Another is storing hydrogen fuel at the track. A further, potentially bigger, issue is the question of who wants to run hydrogen? One commentator reckons that if the European Union moves the ban on the sale of new internal combustion engine cars, or even bans them altogether, hydrogen as a fuel is dead. He is probably right, but I'm not so sure.

For me, the key is that, traditionally, rule sets are introduced with a target lap time of 3m30s at Le Mans. It's the average race speeds that are studied, and what the track is comfortable with. Yet the pole position time for this year's race was 3m23.166s, and the quickest race lap was a 3m26.063s, both set by a Cadillac V-Series.R LMDh. The latter was 1.155 seconds quicker than the previous Hypercar race lap record at Le Mans set in 2023. Extrapolating these figures, if a team is able to gain around half a second per year, it is conceivable that they will be racing in the 3m22s by 2032, and hydrogen will need to be considered capable of winning Le Mans overall by then.

So, we need to take time out of the cars, and that points towards a new rule set before 2032. We also have a lot of manufacturers involved in Hypercar, eight this year and three more coming. No one believes they will all stay as, with only three spots available on the podium, the company boards will soon tire of seeing no visible return on their expenditure.

This year it looked as though Ferrari might lock out the whole podium by early Saturday evening, which would have accelerated that run for the exit. That goodness that didn't happen.

The exercise I wondered was: what will race at Le Mans in 2040? Which of the current manufacturers will still be around at that point, and what size will they be? Chinese car makers are already influencing sales, both at home and in Europe, where cheaper build costs and aggressive pricing strategies are hurting the established companies. Will Porsche and BMW still be big enough in 2040 to stomach parallel racing seasons in the IMSA Sportscar Championship and WEC? I don't know, but it's likely their programmes will be scaled down, together with those of Honda, Alpine and maybe even Toyota, too.

Long-term view

If the Chinese companies decide to race – and the ACO is actively pushing for them to join by introducing Hypercars to the Asian Le Mans Series so they can learn how to run them – then you also have to assume some kind of enhanced electrification. I would guess by then a full electric Le Mans car will be possible, with the advances in battery technology that are coming. ICE will play an important role as well, with a powerful hybrid system and CO_2-free, or neutral, fuel. There is clearly a need for something else too, so let's include hydrogen.

The engineering school at Cranfield University in the UK had a hydrogen-powered prototype as its latest group design project, so is clearly looking to give its students an insight into the technology. Formula Student, meanwhile, remains a predominantly electric racing series in Britain, while the manufacturers are pivoting back towards ICE for their production cars as that's what the buying public currently wants.

Disappointingly, I didn't reach a conclusion as to what, or who, will race at Le Mans in 2040, other than if everyone is agreed that multiple fuels serve multiple functions, it might be a good idea to have racing reflect that trend. If so, it might as well start now.

What will race at Le Mans in 2040? Which of the current manufacturers will still be around at that point, and what size will they be?

Ferrari's playground

The Prancing Horse won at Le Mans once again, but there was more to the race than meets the eye

By ANDREW COTTON

Graphs by PAUL TRUSWELL

For a while there it looked as though Ferrari would dominate the final standings with a 1-2-3 result, but the 24 Hours of Le Mans rarely works like that. The 499Ps worked their way into the top positions within the first four hours of the race after qualifying poorly, using their exemplary long run form to good effect in the opening portion.

They remained at the sharp end for much of the race, too; only one Porsche 963 was able to keep up with them. The other contenders, meanwhile, fell by the wayside, hampered by a lack of performance in at least one area, or three in Alpine's case, including downforce, traction and straight-line speed. Ferrari wasn't top of the pile in any of these areas, but was excellent on a full stint length.

After sterling work by the AF Corse team in the practice sessions to cure a set up issue that left the cars struggling on tyre wear during a triple stint, tyre supplier Michelin was stunned to see every one of the 499Ps run three stints from the start. Michelin engineers cleared them to go for a third stint from the second pit stop of the race.

Ultimately, the race result was decided in favour of the privateer AF Corse team and its drivers, Robert Kubica, Yifei Ye and Phil Hanson. Kubica became Poland's first overall Le Mans winner, and Ye the first for China. It was also vindication for both drivers who lost the LMP2 lead on the final lap in 2021. Porsche finished second courtesy of Laurens Vanthoor, Kévin Estre, who put in an incredible first stint to pull the car into contention, and Matt Campbell.

The factory Ferrari AF Corse team finished third, with 2023 winners, James Calado, Alessandro Pier Guidi and Antonio Giovinazzi, guiding their wounded car over the line, nursing an engine issue that threatened to knock them out of the race altogether. Behind them finished the sister no.50 Ferrari, featuring last year's winning crew.

However, that car was disqualified on Monday evening, when it was found to have four bolts missing in its rear wing support, which allowed the rear wing to flex by 52mm, far beyond the mandated 15mm limit. Despite claims from the team that the omission offered no straight-line advantage, the stewards highlighted that the no.50 car hit its highest top speed on lap 380 of 387, after the team had noticed a crucial bolt was missing. Ferrari responded by saying that the no.50 car achieved that speed while in the slipstream of the ailing no.51.

Upper hand

From the start of the weekend, it was clear Ferrari had the upper hand in terms of race performance. Stories flooded the paddock of the immense straight-line speed of the 499P, but there was no way we were ever going to see that proven ahead of the weekend. The Balance of Performance for the race was locked in early. It looked at two areas: firstly, the FIA homologation parameters of weight, power and aerodynamic efficiency, all of which were fixed and unwavering. Secondly, top speed, adjustments to which could be made if anything amiss was spotted.

'We wanted to remove any incentive from WEC performance results going into Le Mans and avoid sandbagging,' said the ACO's competition director, Thierry Bouvet.

'We wanted to remove any incentive from WEC performance results going into Le Mans and avoid sandbagging'

Thierry Bouvet, competition director at the ACO

The privateer AF Corse team took victory as the factory team settled for third and fourth. Only Porsche was able to challenge the 499Ps, and only with one of its three cars, securing second place while the rest of the 2025 challengers faded into the background

At the finish, Porsche was the only manufacturer capable of separating Ferrari on the podium

The lack of the so-called rolling BoP was one of the root causes of concern in the paddock ahead of the race

Gaps between Hypercars in seconds

'[We wanted to avoid manufacturers] thinking that if they sandbag enough [in the opening three races] they will get a good BoP at Le Mans.

'Secondly, Le Mans is quite [a leveller of] car performance. The track clearly has different sensitivity to weight and power, it is easier on performance between the brands, so we kept the same principle, the same homologation parameters, as last year. That was what we did for this year, and the manufacturers were told.

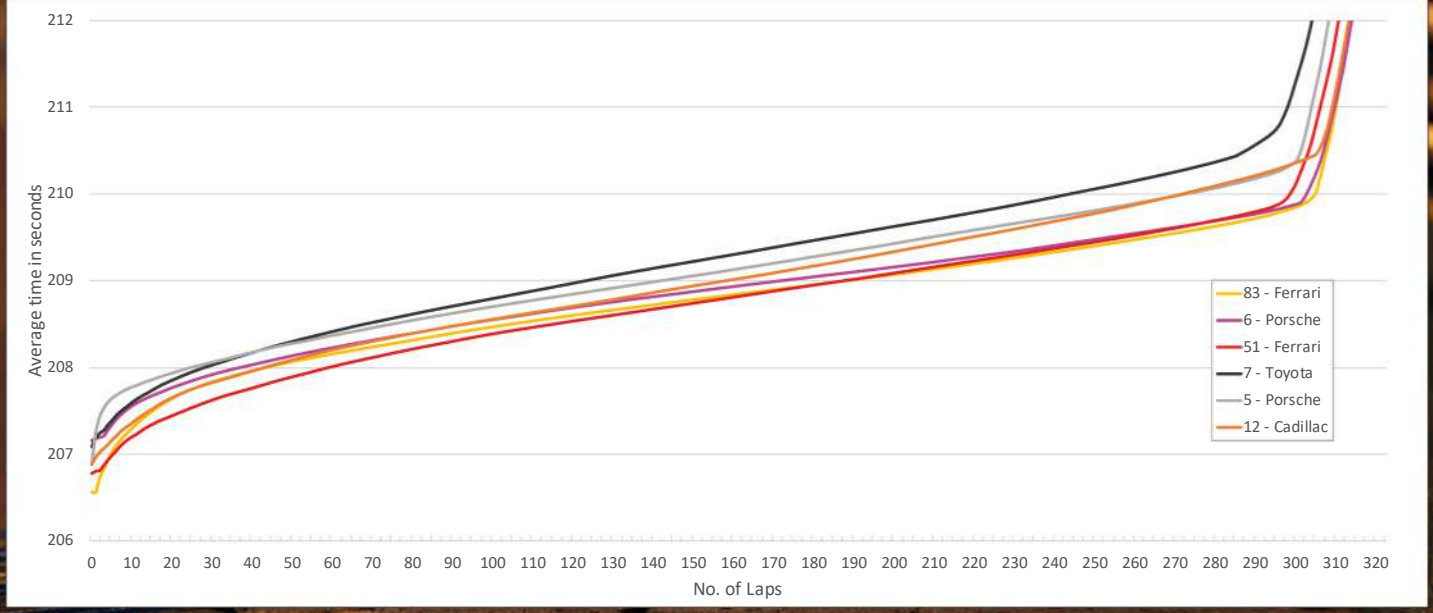
'An additional thing [was that] we did a top speed compensation. From Le Mans 2024, we adjusted the field to an average top speed. That's it.' It was the same process as in 2024, without the lap time adjustment.

The lack of rolling BoP was one of the root causes of concern in the paddock ahead of the race. However, the system has not stopped Ferrari from winning each of the first four of the 2025 FIA World Endurance Championship races.

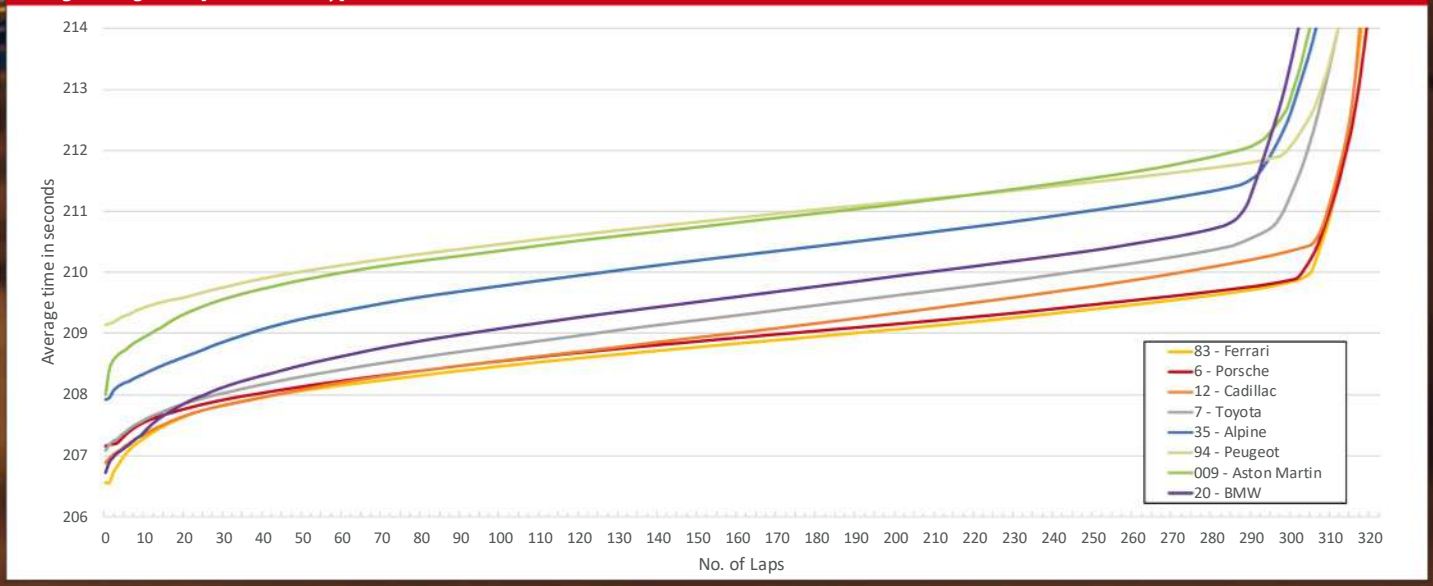
The Hypercars ran with more power than last year, due to the withdrawal of lower performing cars. The aero efficiency was measured in the wind tunnel with minimum wing angle, but the wind tunnel can only provide a maximum speed of around 250km/h, while most Hypercars at Le Mans are capable of around 350km/h.

One of the Ferraris was clocked during the race at 364km/h, though the manufacturer claimed this was a mistake, and the speed is

Rising average top six Hypercars



Rising average comparison, all Hypercar manufacturers



Stint lengths

			12 lap	13 lap	Other	Last 13-lap stint
83	Hanson / Kubica / Ye	Ferrari	20	7	5	7am
6	Estre / Vanthoor / Campbell	Porsche	12	15	1	7am
51	Giovinazzi / Pier Guidi / Calado	Ferrari	24	5	3	7am
50	Nielsen / Fuoco / Molina	Ferrari	21	5	4	2am
12	Stevens / Lynn / Nato	Cadillac	24	1	9	7am
7	Conway / Kobayashi / De Vries	Toyota	28	1	3	8pm

not found on the results list for the event. Ferrari did top the chart through the speed trap, though, both Miguel Molina and Antonio Giovinazzi clocked at 349km/h, with a Peugeot 9X8 third at 346, Cadillac and Porsche at 345, BMW and Alpine at 344, Toyota at 343 and Aston Martin bringing up the rear at 342km/h.

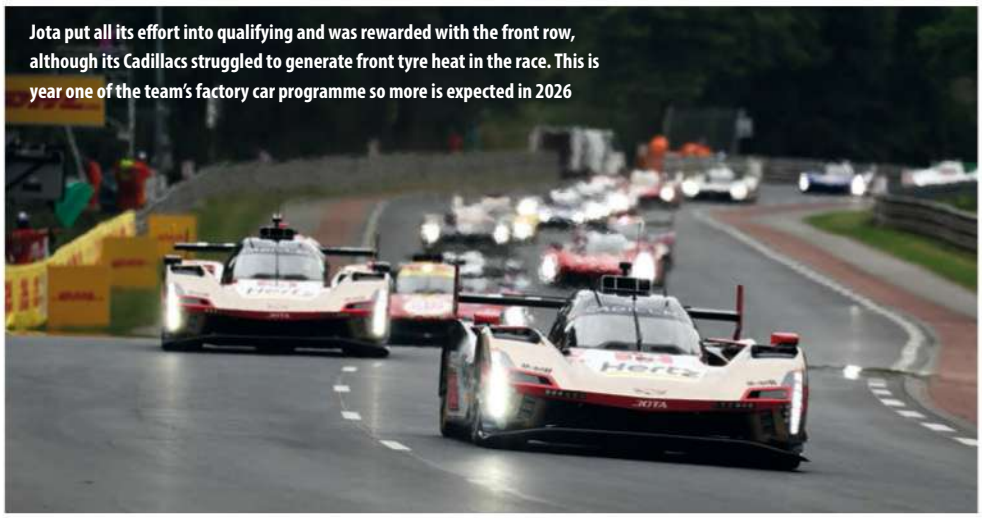
The 100km/h difference between speeds measured in the tunnel and on track is critical, as it's the biggest influence in dealing with traffic at Le Mans, and therefore raceability. To try and mitigate this, the organisers used the top speed analysis from 2024 to help balance the cars for the 2025 event.

The FIA has tried to stamp down on the topic of aeroelasticity in Formula 1 by introducing tougher deflection tests, but in sportscar racing there is still the possibility to bend and flex. Like the FIA in F1, the Le Mans scrutineers rely on their static tests to measure the cars' wings, but few could find any other way of explaining how Ferrari was able to achieve its high top speed, especially taking into consideration its acceleration up to 250km/h.

Qualifying flyer

There was a new qualifying format, similar to that of Formula 1, although in typical Le Mans fashion, it took place over two days. The first qualifying session saw the top 15 cars go through to a second session, held on Thursday,

Within the first hour, it became apparent that the Peugeots and Alpines didn't have the race performance that was expected. Neither did the Wayne Taylor Racing Cadillac



Jota put all its effort into qualifying and was rewarded with the front row, although its Cadillacs struggled to generate front tyre heat in the race. This is year one of the team's factory car programme so more is expected in 2026

The no.51 Ferrari finished on the podium, despite an engine issue that threatened to eliminate it at the end. The sister car was excluded post-race for a rear wing infringement

and the top 10 of those progressed to a final shootout. Cadillac consequently focused its pre-race preparation on qualifying, knowing this was the biggest win it could reasonably expect with two teams new to its Le Mans programme, Wayne Taylor Racing and Jota, alongside the experienced Action Express team.

The Jota-run factory Cadillac V-Series.Rs put on an impressive display and locked out the front row. The team knew how to prepare the cars for qualifying, having worked exhaustively with Michelin to find a set-up that worked over the 13.6km lap. Alex Lynn set a time of 3m23.166s, slower than the 3m22.742s posted by Jack Aitken in the Action Express Cadillac during the first Hyperpole session, but quick enough to take pole ahead of his team mate, Earl Bamber.

BMW lined up third and 10th, Ferrari fourth, 11th and 13th, Alpine fifth and 12th and Toyota sixth. Porsche, meanwhile, managed a best of seventh, Felipe Nasr having burned through nine sets of tyres in qualifying simulation, meaning his co-driver, Nick Tandy, was given the final set of new tyres for the first time when it was his turn to go in the final session. The next-best Porsche was ninth, while the third was excluded for being underweight and had to start from the back of the grid in 21st position.

Toyota was the most surprising result. The Japanese manufacturer is known to be good at Le Mans and topped the times in testing, but needed low fuel and fresh tyres to extract such performance from its car. The team reported that both Toyota GR010 Hybrids were sliding, particularly in the Porsche Curves where they were losing nearly a second to the opposition. The car was heavy at 1053kg, but that's the same weight as it ran in 2024. It had more power below and above 250km/h than last year, but the team was struggling for grip and never really found the solution, so ran off the pace all weekend.

Ferrari said it had a cooling problem with the no.83 customer car in qualifying and that the no.51 works machine couldn't get up to the right power levels. Nicklas Nielsen's fourth place was the best the Italian manufacturer could do in qualifying, though it was clearly focused on the race.

For the first time since 2022, the race was both warm and dry throughout. Temperatures dropped from a comfortable 23degC at the start to 15degC during the night, and track temperature went from 28degC to 22degC overnight. It was at its highest on Sunday afternoon, at 34degC. The competitors all selected medium compound tyres, no one even trying the hard compound in practice, and with 14 sets available for the race, they had to double or triple stint at various times during the 24 hours.

Race pace

It didn't take long for the race to settle and for the true performance of the cars to be shown. Mike Conway in the no.7 Toyota was immediately sandwiched between a Cadillac and a Peugeot, damaging both sides of his GR010 Hybrid, which left it aerodynamically compromised for the rest of the race. A 50s penalty for speeding in the pit lane also didn't help. Meanwhile, Julien Andlauer moved to the front of the field in the no.5 Porsche on the first lap, by the first chicane on the Mulsanne Straight, and Estre worked hard to move his no.6 Porsche up to seventh.

Within the first hour, it became apparent that neither the Peugeots or the Alpines had the race performance that was expected. Nor did the Wayne Taylor Racing Cadillac, though as the team was new to the track, the car and the WEC, expectations were low from the outset. For the French manufacturers, however, it wasn't going to plan at all.

After 10 laps, the Alpine A424s were more than 20 seconds behind the leaders, the Peugeots more than 30 seconds back before Paul di Resta ran wide at the Porsche Curves, hit the barriers and had to pit for repairs.

'We were lacking pace at the beginning, we made some mistakes as a team and drivers, and at the end we paid the price,' said Alpine's sporting director Nicolas Lapierre, after a race punctuated by penalties and driver error. 'At the end the car was better, when the track rubbered in, but we didn't have the pace to be at the front.'

Ferrari show

It took until the fifth hour for Ferrari to exert its authority and run in first, second and third. Only the no.6 Porsche could mount a challenge, the other two Penske-run factory 963s curiously off pace. During the pit stop sequences others led briefly but, by Saturday night, it was clear this was another Ferrari show.

Slightly off strategy, the Porsche spent time in the lead throughout the race, but only during the pit stop sequences. It looked like

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the Ferraris were just biding time, not showing their true performance until it was needed. That drove its rivals to distraction as they could all see they would not be able to challenge on a level playing field.

Rivals also noticed that during the night the Ferraris stayed off the kerbs, reducing stress on the tyres and the suspension, yet still maintaining high speeds. They also didn't experiment with tyres, running mainly on mediums throughout. Nielsen did try softs during the night in the no.50 but quickly switched back to mediums after his triple stint.

Spins and things

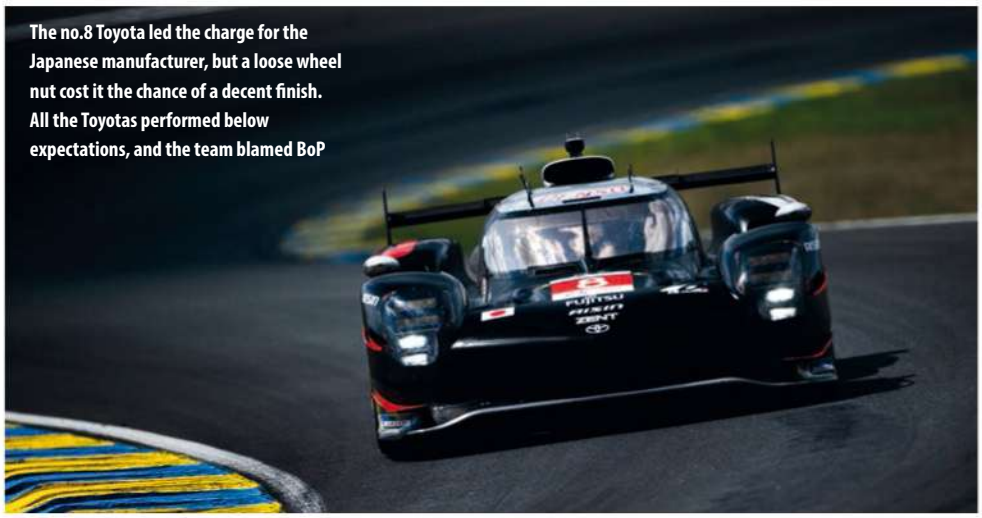
The only time it looked like it might unravel for Ferrari was when Pier Guidi spun the no.51 car from the pit lane entrance into the gravel on Sunday morning, which cost some time. Meanwhile, Toyota was in the process of throwing away the minute chance it had to score a result when a wheel nut broke away from Ryō Hirakawa's car as he exited the pits. That meant the Japanese driver had to do a complete lap slowly, which put paid to any chance Toyota had.

BMW lost time with engine and hybrid issues on its cars, while Cadillac slowly faded into the background. The rumbling American cars were struggling to generate heat into their front tyres, despite the very small drop in temperature during the night. Cadillac even went to a combination of soft tyres at the front and mediums at the rear to try to generate heat, but that didn't work either. Norman Nato did a triple stint in the no.12 car with decent lap times in this configuration, but the team reverted to mediums when Will Stevens jumped aboard. While Ferrari and Porsche are particularly good at switching on the tyres, Cadillac knows it now has to invest heavily in the car to get up there.

Ferrari's factory team did start to lose ground in the closing stages of the race. The no.51 car ran into an engine issue that James Calado said could have ended its hopes even of finishing. However, the team told Antonio Fuoco in the no.50 car to dial it back a bit and follow the ailing no.51 over the line.

'It was another page of Ferrari history,' declared Ferrari's head of endurance, Ferdinando Cannizzo, after the race. 'It is a mix of emotions, it was difficult to survive. We were strong in race pace. In qualifying we did our best, it was not brilliant, but enough for a 24-hour race. After four hours we recovered all the positions and the race was dominated by the 499P.

'One car had no problem, we adjusted car no.50 – an issue with the brakes – so we lost some seconds. There was some indication to re-set the braking system, and that was it. On no.51 we had a potential issue on the engine and, at the end of the race, as we could not grab second position we decided to hold on.



The no.8 Toyota led the charge for the Japanese manufacturer, but a loose wheel nut cost it the chance of a decent finish. All the Toyotas performed below expectations, and the team blamed BoP

'The race doesn't care if you are happy, mad or sad, it just carries on regardless. We just had to focus on what we could control'

Jonathan Diuguid, managing director at Porsche Penske Motorsport

'We were strong on consistency,' continued Cannizzo. 'We did not have anything excellent in each area, but the overall package was good enough. The others had better acceleration, downforce or top speed, and we had the combination of it all. It was difficult for us sometimes to overtake. We had to play a lot with the energy in the stints and we had to take it into consideration.

'Some competitors were strong in the beginning but the execution wasn't perfect. I have congratulated car no.6, they did an excellent job. They finished the race and fought to the end. We were surely not the fastest car but, as a package, we could optimise the result.'

Three in a row

That result means Ferrari keeps the winner's trophy, having now won three Le Mans in a row, even though this year's prevailing AF Corse car is technically a privateer.

Porsche finished second, despondent it could not take the fight to Ferrari, but happy enough with the podium after the red cars ran into technical issues. Upset on Saturday night at Ferrari domination translated into a podium finish on Sunday as the team knuckled down and focused on its own race.

'The race doesn't care if you are happy, mad or sad, it just carries on regardless,' said Jonathan Diuguid, managing director at Porsche Penske Motorsport. 'We just had to focus on what we could control and that was keeping the cars running, having strong pit stops and the drivers putting in laps where they could. We had a second place for the no.6, but also the no.5 and no.4 were in the top 10 with other issues, and penalties. I expected a tough fight and that's what we got.

'Congratulations to Ferrari, they ran a strong race. The no.50 and no.51 had technical issues at the end that dropped them back a bit but, in general, it was a straight fight all day.'

Aston Martin, meanwhile, brought its two Valkyries to the end of the race, a tremendous achievement for the British team on the car's Le Mans debut. Adam Carter, head of endurance at Aston Martin, commented, 'We are in the one per cent area,' meaning the team is close to the leaders and is now looking at the small details that will allow it to challenge for the top positions. For a first run with a new car, the team was justifiably proud of its result.

Although BoP talk is banned in the paddock by the FIA, there is plenty of other ways to say what needed to be said: 'As expected, under the specific regulatory framework of the 24 Hours of Le Mans, the pace of the Peugeot 9X8s during the test day was not competitive enough,' read Peugeot's press release.

Toyota was even more oblique about the situation: 'On the 40th anniversary of Toyota's first Le Mans participation, the team took the fight to its rivals with effective strategy, precise driving and fighting spirit,' read its press release, 'but a promising race ultimately did not meet expectations as misfortune and a blistering pace at the front thwarted the team's charge.'

It was patently obvious that some teams were unhappy with this year's BoP, while others clearly need to work on their own performance and reach their maximum potential before they can justifiably say anything. Overall, although Ferrari dominated and took a deserved win, the podium had a little variety to it. That was a better result than looked likely on Saturday evening.

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Double delight

Manthey successfully defended its LMGT3 win in 2025 with a polished performance from the driving team, captained by Richard Lietz

By ANDREW COTTON, Graphs by PAUL TRUSWELL

The winning Porsche at the start of the longest race. The team running the car focused on driver development in the simulator before the race rather than car set-up, with startling results

The Manthey team took victory in the LMGT3 class at Le Mans this year. It was a pretty dominant display by a team that worked hard on driver development in the simulator pre-race to ensure it had no weak link, or stint.

Richard Lietz, who is fast becoming one of the most successful drivers at Le Mans, said that he had never been so well prepared, having spent a good deal of time bringing his co-drivers, Riccardo Pera and Ryan Hardwick, up to speed in the Porsche 911 GT3 R. Lietz and Manthey won the first LMGT3 race at Le Mans in 2024, so both knew they would face stiff opposition from their rivals.

Naturally, Balance of Performance was a key topic in the lead up to the event. The FIA's homologation parameters were used, but the ACO openly admitted that it struggled to measure the cars aerodynamically.

In Hypercar, the bodywork tolerances are +/-3mm, but in LMGT3 it is +/-5mm, which would make a big difference in the wind tunnel. That left the high speeds these cars are capable of difficult to judge accurately.

'It is also linked to drivers,' says the ACO's Thierry Bouvet. 'We have Bronze, Silver and the pro drivers. The task is more complex because you have more trustable data in Hypercar because everyone has Platinum drivers, so the starting point is closer. There is no car with the engine at the front or back. It's a bit more complex because of this.

'In Hypercar the bodywork tolerance is +/-3mm, and for some of them it's challenging to get into that window. For LMGT3, it's double that. How are we supposed to achieve exact aero figures, while the deviation of the bodywork can be double that of Hypercar? We had the discussion with the LMGT3 manufacturers, that there is something striking, that we need to make the bodywork tolerance tighter.'

Teams are allowed to homologate a Le Mans-specific gear ratio set, but the difference between that and a regular set is minimal.

Preparation is key

Lexus arrived better prepared after its Le Mans debut last year, the Auto Sport Promotion team saying it learned valuable lessons in 2024. One Lexus RC F GT3 was extremely quick last year, the other less so. ASP therefore worked hard on understanding the aero set-up for its cars. That work put

Stint lengths

			10 lap	11 lap	other
92	Lietz / Pera / Hardwick	Porsche	26	5	3
21	Rovera / Mann / Hériau	Ferrari	18	12	5
81	Eastwood / Van Rompuy / Andrade	Corvette	29	2	3
27	Drudi / Robichon / James	Aston Martin	26	3	5
87	López / Schmid / Umbrărescu	Lexus	5	23	3
90	Bachler / Hartog / Au	Porsche	24	5	5

'In Hypercar the bodywork tolerance is +/-3mm, and for some of them it's challenging to get into that window. For LMGT3, it's double that'

Thierry Bouvet, competition director at the ACO

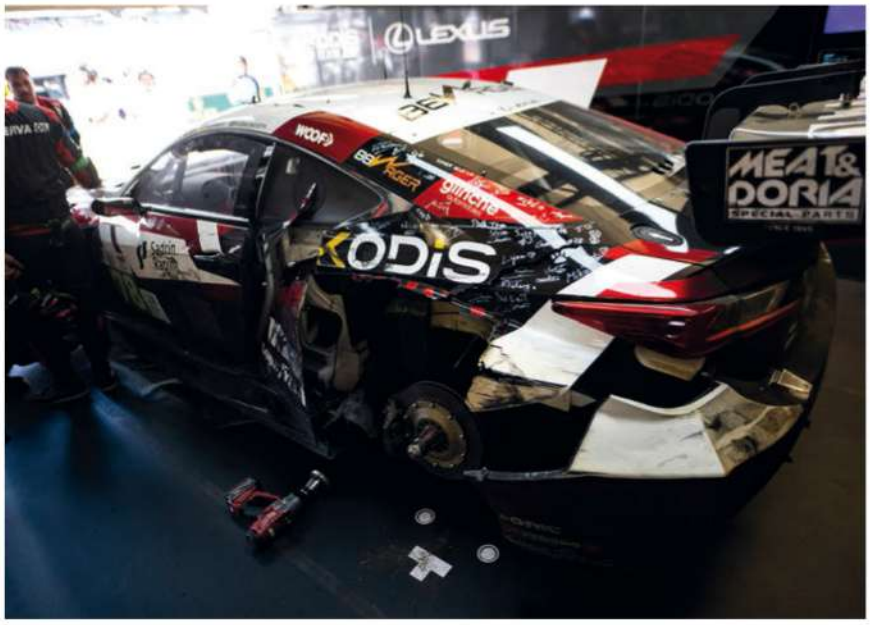
them at the head of the table for the competition, BMW lamenting it was only going to be able to fight in the top 10 if the Lexus and Ferrari 296 GT3s proved unreliable.

Upper hand

As it turned out, it was Porsche that had the upper hand in terms of pace and BMW was competitive after all. The winning Manthey car didn't post the fastest overall lap time (that went to the pole-sitting Aston Martin Vantage GT3 Evo) but was strong during the night. Having led for the first time on lap 73, it then fought with the no.46 BMW M4 GT3 Evo – until that hit a rabbit which broke its cooling system – and the no.21 AF Corse Ferrari. Manthey moved into a commanding lead on lap 208 and led the last 134 laps to the flag.

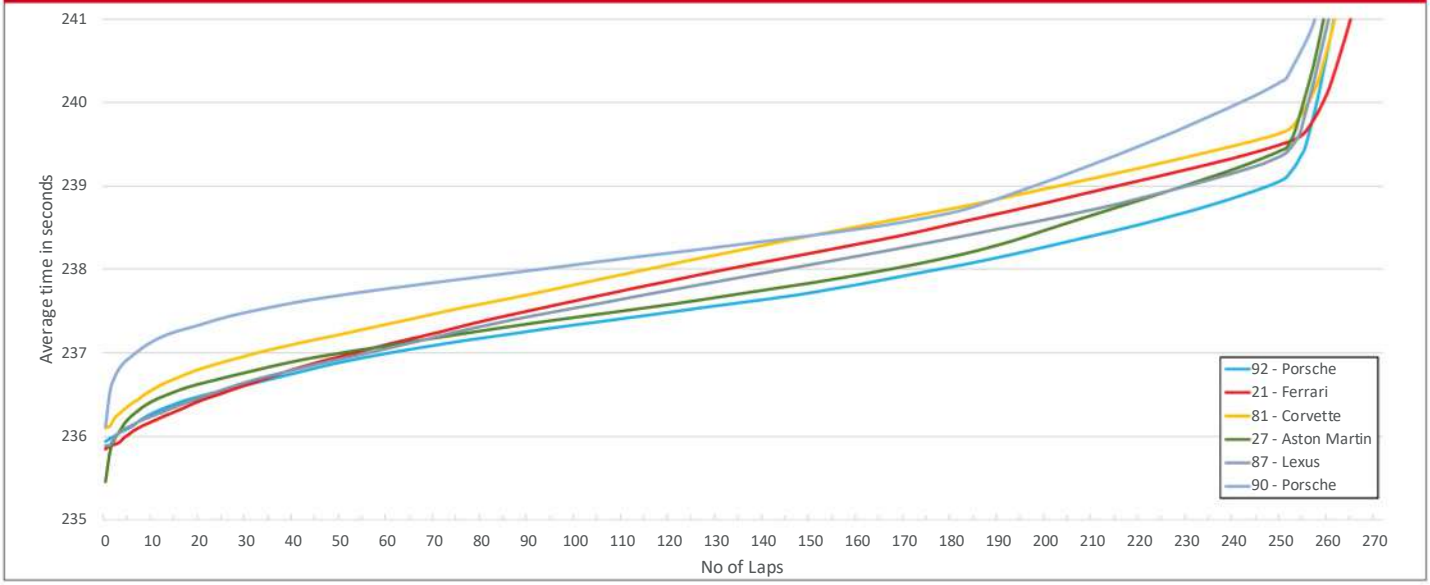
Post-race, rivals pointed to the fact that the Porsches could go faster, for longer, than all the others, save for the Lexus which finished fifth, and that they didn't stand a chance in almost perfect race conditions. The figures don't necessarily back this up though. The rising averages graph shows the Porsche was, indeed, the fastest of the top finishers, but it focused on 10-lap stints, compared to the second-placed Ferrari that was more evenly split between 10 and 11-lap stints. The outlier is Lexus, which did 23 stints of 11 laps, stretching the fuel window, while also posting decent lap times compared to its rivals.

Ferrari and Lexus started out as favourites but, although Lexus could go further on a tank of fuel, and was quick, it encountered damage, while Ferrari kept its nose clean and finished in second place, 30s behind the winning Porsche



The Lexus may be an old design, but everything on the car was new, suggesting a big push from the manufacturer and its ASP team for this race. The car was quick, and the team chose an 11-lap strategy, but finished fifth

Rising average LMGT3 top six



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Pole position

Inter Europol returned to winning ways in LMP2

By ANDREW COTTON

Graphs by PAUL TRUSWELL

Despite picking up a speeding ticket, the Polish squad was rarely out of contention for a repeat of its 2023 win

The Polish Inter Europol team crossed the line first, having led for much of the race, yet it wasn't a straightforward victory. The no.34 ORECA 07 Gibson led 216 out of 367 laps, but then driver, Nick Yelloly, locked up in the pit road, picked up a drive-through penalty for speeding in the pit lane and re-joined in second place, only to re-take the lead eight laps before the flag. The fact that in what has become a one-make category he was able to win, even with the penalty, speaks volumes.

The LMP2 category is open to other manufacturers, but every entry has been an ORECA chassis for the last three editions now. Goodyear tyres are standard throughout the class, and there is only one choice of slick. Differences between the cars therefore come from the driver line up, with one Silver or Bronze in each team. They have to complete a minimum number of hours behind the wheel in the 24-hour race but, once they have done their time, it's down to the professional drivers, in this case Nick Yelloly and Tom Dillmann, to finish the job.

Clearly, there is something about the Inter Europol car that works particularly well at Le Mans. Looking at the rising averages graph, it was fastest for more of the race than any other car around it in race conditions.

It was beaten to pole position by Mathias Beche in the TDS Racing Pro-Am entry, but swept into the lead on lap 12. RLR Msport and VDS Panis Racing had turns in the lead on Saturday but, by Sunday morning, the Polish car was firmly in control, leading for 128 laps straight, before Yelloly's drive-through penalty offered a glimmer of hope to the others.

Sitting duck

That put the VDS Panis Racing entry, which started 11th but challenged for much of the race, back into the mix briefly, but a broken front suspension left it a sitting duck in the sights of the erstwhile leader. A suspected broken toe link meant the car lost time in the last 20 minutes, allowing Yelloly to re-take the lead. 'We rolled off the trailer in good form and started to chase and finished back where we started,' said the British driver.

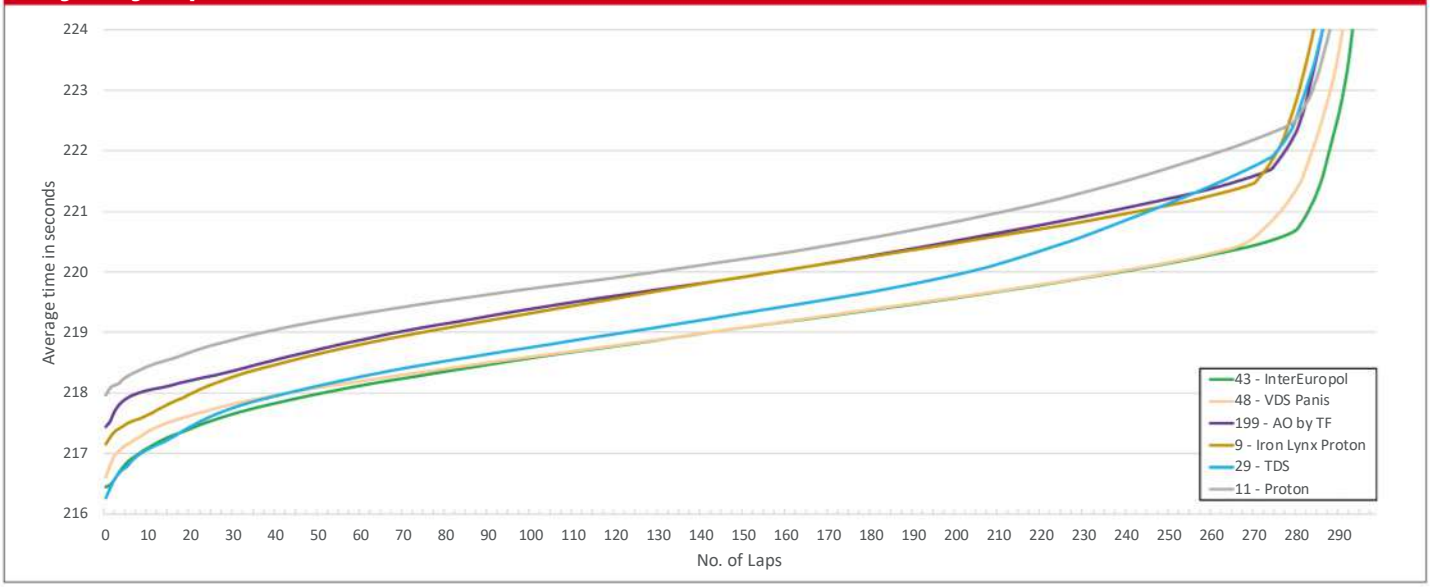
'We were getting slower and slower through the practice session but ended up with a rocketship in the race.

'VDS had a strong racecar, particularly when it was hotter. Early in the morning we were flying, and you could do what you wanted with [the car], but then it heated up and we struggled a bit more, particularly at the rear axle. Kuba [Smiechowski] is our Silver [driver], he's won it twice and is great, particularly here. Once we had burned his time, it was me and Tom. It was tit-for-tat all race and credit to VDS for pushing us so hard.'

The two cars ran at the head of the field for the majority of the race and, despite the suspension issue, both finished a lap ahead of the competition, led by the Pro-Am winning car from AO by TF Sport.

The RLR Msport entry went out of contention when it was hit by another competitor, while the Nielsen Racing team triggered the race's only safety car period when it crashed at Tertre Rouge overnight. IDEC Sport, meanwhile, had both its cars retire, each having lost a wheel.

Rising averages top six finishers LMP2



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Paddock round-up

Highlights from a busy press conference day in the sportscar racing year

By ANDREW COTTON

Friday at Le Mans is one of those days where time is stolen. The press conferences are tightly packed, sometimes overlapping, and the sheer size of the facility, coupled with high temperatures this year, meant choices had to be made as to where and what to attend.

The ACO kicked off the day with its conference in the Marie Marvingt football stadium at 11am. There, it confirmed the tender processes had been completed for the new LMP2 regulations coming in 2028. **ORECA** and **Ligier** won the right to build chassis and **Gibson Technology** the powertrain. No confirmation was given of who Gibson chose to supply the gearbox and electronics. The British company refused to be drawn on who it had selected, saying it wanted to focus on the race that weekend.

However, FIA technical director, Xavier Mestelan Pinon, was on hand to answer the inevitable questions: 'It was driven for efficiency reasons,' said the Frenchman, talking of the decision to bring the engine, gearbox and control unit into a combined tender. 'To be sure that the engine manufacturer will work best with the electronic supplier and so on. For them, and also for us and for the ACO, it's easier to manage.'

Mestelan Pinon also confirmed the ORECA and Ligier chassis would be balanced against each other, as the current regulations permit, though it's clear the latter will have to invest heavily to entice teams to switch from ORECA, which has been hugely successful under the current rule set established in 2017. Dallara was also rumoured to be trying to lure teams away but, when that didn't materialise, it did not submit an application.

Also confirmed at the ACO press conference was news that **Le Mans Classic** will become an annual event, alternating between Classic Heritage and Classic Legends, which will allow LMP1 and LMP2 prototypes, as well as GTs of the 2010s, onto the grid.

The **Asian Le Mans Series** will welcome Hypercars to its series for the 2026 / '27 season. The Hypercar entries will be for Pro-Am crews consisting of at least one Bronze-graded driver. The objective is to bring teams up to the standard required to run Hypercars and then invite them to compete in the FIA World Endurance Championship.

Finally for the ACO's announcements, **Toyota Gazoo Racing** confirmed its collaboration with **Mission H24**, the ACO's rolling test bed for hydrogen-powered mobility. Toyota will help with the development of the aerodynamics and cooling systems for the car. The announcement coincided with confirmation of a hydrogen category at Le Mans in 2028, although the FIA was rather keen to push that date closer towards 2030.

From there, it was on to **McLaren** at 1pm, which launched its Hypercar programme for 2027 in partnership with Dallara, as predicted in the March issue of *Racecar Engineering*. The surprise here, though, was that the British manufacturer confirmed it will partner with **Autotecnica Motori**, the Italian company that built the engine for the Lamborghini SC63 out of its original engine built for GP2. McLaren has an existing relationship with Ricardo in the UK, and its own engine development centre, but will use neither of these two facilities for its Le Mans programme.

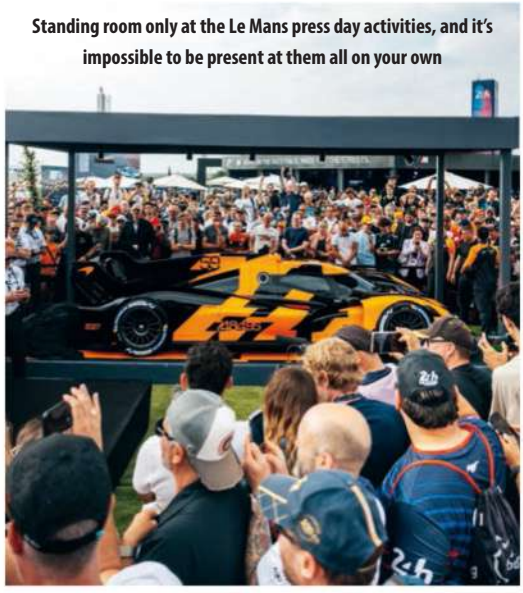
McLaren personnel on hand confirmed the engine will be brand new, and the only link with the production Artura is that it will be a V6. No other details were forthcoming.

There will undoubtedly be a desire for the team's current F1 drivers, Lando Norris and Oscar Piastri, to test the car, and maybe race it at Le Mans, but the 2026 schedule announced sees date clashes with the test day and the race, and no guarantee from the FIA that the Le Mans race weekend will be kept free in the future.

Elsewhere, **Genesis** revealed its top leadership team for the 2026 season, including Anouck Abadie as team manager and Justin Taylor as chief engineer. Taylor was a race engineer for Chip Ganassi Racing in 2024, working with Cadillac, and won Le Mans with Ferrari in 2023. Before that, he was a long-time Audi data and race engineer in the LMP1 era before moving to former Audi partner Joest for its Mazda IMSA programme, and then Ed Carpenter Racing in IndyCar.

On to **Ford** at 4pm, where the American manufacturer confirmed it had chosen the ORECA chassis for its LMDh car, also predicted by this magazine in January. The team has nominated Dan Sayers, formerly of Prodrive and latterly programme director at Red Bull Powertrains, as its lead engineer on the programme. The Briton had only been in the job for eight days when the announcement was made, so has his work cut out to bring the car and programme up to speed. Rumours swirled around the paddock regarding which team would run the car in the race. Chip Ganassi Racing remains the favourite to land the gig, re-uniting his team with the Blue Oval, but at least three others have their hats in the ring.

Apologies to Ferrari, BMW, Porsche and Toyota for missing their press conferences on Friday.



Standing room only at the Le Mans press day activities, and it's impossible to be present at them all on your own

Deflection reflection

F1's big rule change of 2025 didn't immediately alter the pecking order. So, what was all the fuss about?

By DANIEL LLOYD

After the ninth round of the 2025 Formula 1 season, Mercedes team principal, Toto Wolff, said: 'Maybe sometimes we try to believe there is a magic bullet in Formula 1 that's going to solve everything, but it's not the case.' His frank comment referred to the FIA's introduction of stricter front wing flexibility tests ahead of that weekend's Spanish Grand Prix.

Wolff, and everybody else, had just witnessed McLaren take its third one-two result of the year. It came despite a lot of pre-race attention on whether the tougher tests would erase part of the Woking team's advantage. Instead, McLaren furthered its World Constructors' Championship lead and gave the impression that its MCL39 has enough tools in the box to ride out a mid-season regulation tweak.

The events of Barcelona made the 'flexi wing' storyline feel like a storm in a teacup. However, it is understandable why it received so much airtime. The performance margins in F1 are *so* small, the cars *so* sensitive to adjustment, that even the most subtle of edits to the 179-page technical rulebook is bound to receive near-forensic analysis. This is especially pertinent in the final season of a rule set, when car designs across the grid are at their most convergent. The fact this saga arose from complaints about rival teams abusing the permitted aeroelasticity of wing components only helped fan the fire.

McLaren's recent grand prix successes have put the MCL39's engineering under the microscope, notably how the team uses aeroelasticity in some of its aerodynamic elements

The amount of [front wing flap] deflection was reduced to 3mm, a decrease of 40 per cent… as a compromise between tightening a loophole and ensuring parts didn't become significantly heavier

It also played out over multiple stages, as measures to monitor and curb bodywork flexibility were rolled out over multiple grands prix, protracting its time in the public spotlight. Now that the full extent of the FIA's clampdown has been implemented, it is worth exploring why the rule changes were made and what gains the teams were attempting to extract.

'Generally speaking, we prefer not to change things during a year,' says Nikolas Tombazis, single seater director at the FIA. 'But we also are conscious of the fact that, especially in close championships, there are quite a lot of allegations, like last year.'

During the 2024 season, onboard video footage emerged of the McLaren MCL38's rear wing deforming in such a way at high speed that the slot gap increased. This, the team's rivals argued, would reduce drag on the straights. McLaren duly altered its design, despite the wing complying with all the relevant FIA deflection tests.

However, that wasn't the end of the flexi wing saga, as footage of the front wings on multiple cars showed elements rotating significantly under braking. This compelled the FIA to act, as it attempted to stop teams from deliberately making their wings flex and simultaneously halt the rumour mill.

The key numbers

There are multiple strands to the FIA's ongoing aeroelasticity investigation. One concerns the front wing, split into bodywork and flap deformation, while the other concerns the rear wing. At the rear, the FIA wrote a new point in the 2025 technical regulations to reduce the amount of flexing. It initially said that when 75kg worth of vertical load was applied on the main plane, the slot gap could not be more than 2mm. After camera footage from the season opener in Australia found the wings to be flexing more than expected, the FIA enforced tighter margins for rounds two and three in China and Japan. There, the slot gap allowance was reduced to 0.75mm and 0.5mm respectively, though a 0.25mm tolerance was allowed for China to let teams adapt to the new tweaks.

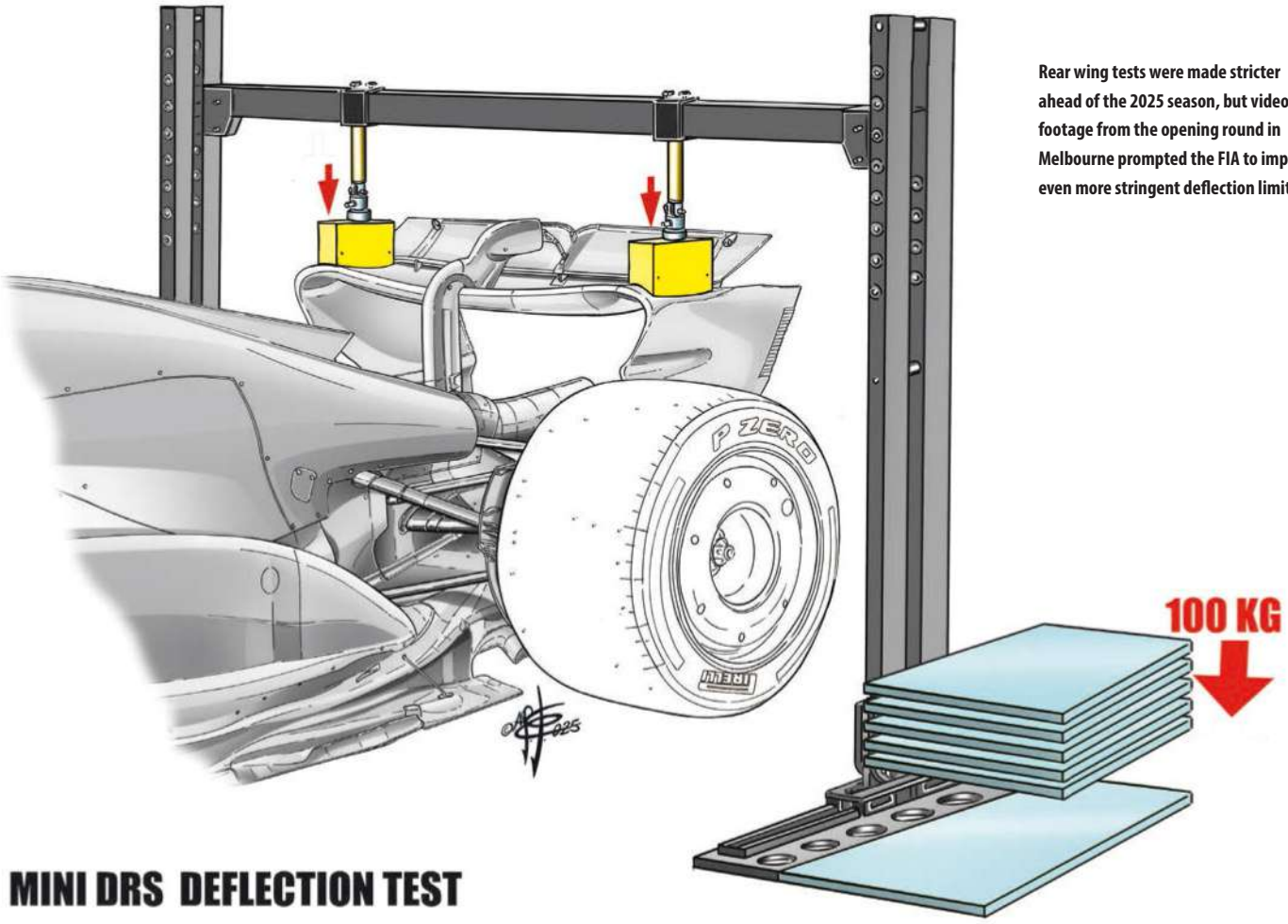
Regarding the front wing, no changes were made to the regulations between 2024 and 2025, until a revision published on 26 February this year. Before that, the rules stated the front wing bodywork could flex by no more than 15mm when a 100kg load was applied symmetrically on both sides, and no more than 20mm with load applied on one side. The February change stated that, from round nine in Spain, the amount of deflection under the same 100kg load could be no more than 10mm on both sides and 15mm on one.

Additionally, revisions were made to address how much the front wing flap may deflect. The first version of the 2025 regulations said that 'any part of the trailing edge of any front wing flap may deflect no more than 5mm, when measured along the loading axis, when a 60N point load is applied normal to the flap.' But then for the Spanish GP, the amount of deflection was reduced to 3mm, a decrease of 40 per cent. The FIA reached that number as a compromise between tightening a loophole and ensuring parts didn't become significantly heavier.

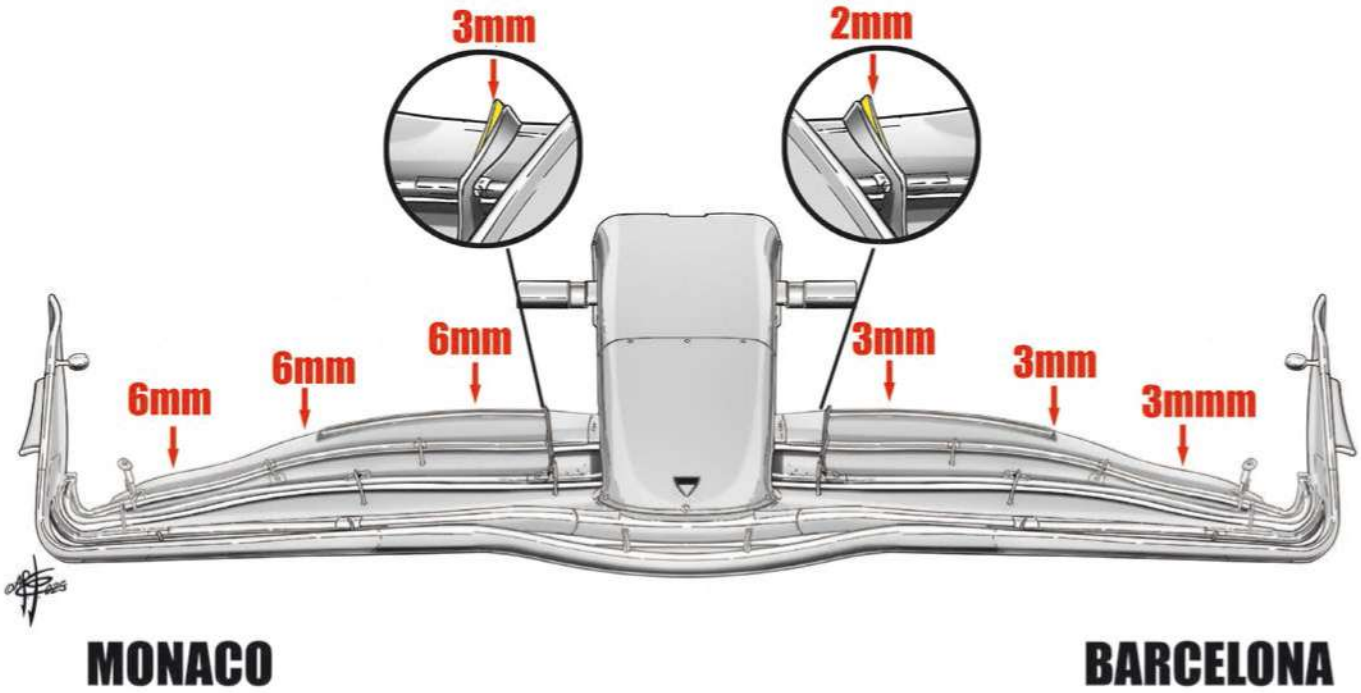
Initial measurements

How did the FIA come to its conclusions? Its first step was to fit cameras to all the cars, aimed at the wings. Circular stickers visible on the wings provide reference points for reviewing the video footage.

Giorgio Piola / FIA



Rear wing tests were made stricter ahead of the 2025 season, but video footage from the opening round in Melbourne prompted the FIA to impose even more stringent deflection limits



Giorgio Piola / FIA

Front wing flexibility was tightened from round nine of the 2025 season in Spain. Note that the original front wing flap allowance was actually 5mm, not 6mm as the graphic shows

'We made some decisions last autumn about roughly where we wanted to arrive, in terms of levels of deformation, so we could see it from the cameras,' recalls Tombazis. 'We were initially expecting not to make an intervention on front wings for this year. But, as the end of the season approached, our measurements indicated with the cameras that there was an increasing trend in deformations that we felt would cause potential complications this year. We felt we had to act.'

The FIA's consideration was to implement changes that would have minimal negative impacts on the teams' parts production. It felt that leaving things as they were would only kick the can down the road and potentially require teams to produce parts during the 2025 season, instead of during the winter when there is more time. This was especially pertinent during the final season of the regulations, when teams are looking to switch focus to the new 2026 cars as soon as possible.

'We felt there were a number of wings that teams had already produced that would be obsolete,' adds Tombazis. 'Conscious of the cost cap, we thought the sensible time was to go for approximately [late spring], when most teams tend to aim for an upgrade anyway. We felt this upgrade should be to the stiffness limits.'

The rear wing flexibility changes were implemented before the front wing because they were less severe and easier to meet.

'The front wing requires completely new front wing main planes, which are very lengthy and expensive components,' explains Tombazis. 'The rear wing is smaller in size, but we believed that most teams would be able to adapt to the rear wing rules just by playing around with their DRS mechanisms. This turned out to be the case.'

For Spain, Ferrari updated the chord-wise and span-wise loading distribution of the SF-25's front wing elements, as well as bringing a re-designed end plate and outboard tip rolls

It meant teams could swallow the FIA's introduction of even tougher rear wing deformation limits in China, despite it occurring between flyaway rounds.

Bending the rules

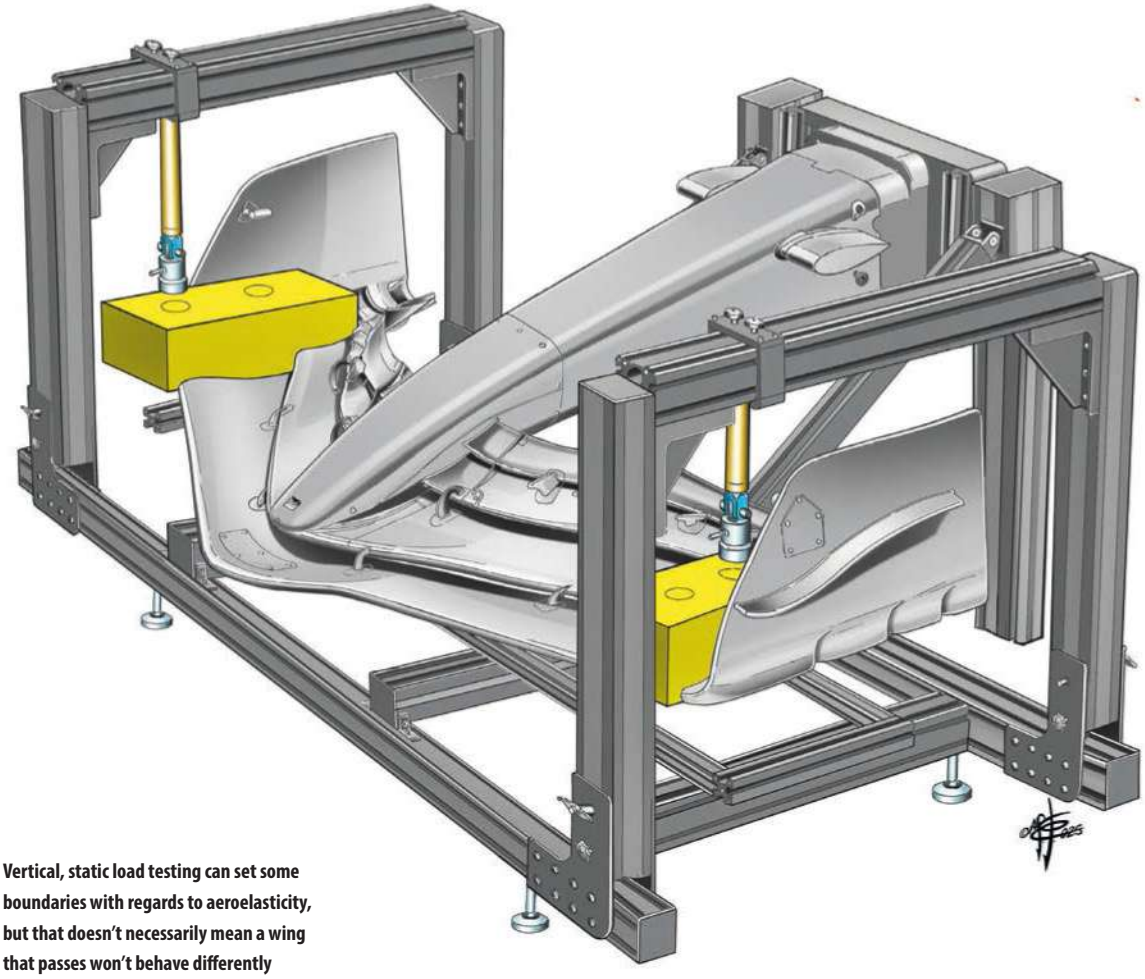
Aeroelasticity it nothing new in Formula 1. Teams have been investigating ways to make their bodywork flex to deliver optimal downforce, drag and stability for decades. Since wings were introduced in the late 1960s, and carbon fibre in the 1970s, there has been potential for aeroelasticity to be exploited. It has occasionally flared up as a topic of technical intrigue, such as in 2007 when the FIA made rear wing slot gap separators mandatory.

In broader engineering literature, aeroelasticity is often mentioned in the context of aviation. Aircraft *must* have surfaces that distort under aerodynamic forces, otherwise they would break apart. The situation is similar for F1 cars; a front wing cannot be infinitely rigid because it would not be able to withstand the massive loads generated at high speed.

Since 2022, F1 cars have generated most of their downforce from underneath the floor. A ubiquitous challenge across the grid with these cars has been to find a suitable compromise between running the cars low enough to be stable through the corners without compromising straight-line speed by increasing drag. This is where having a rear wing that flexes to reduce drag is beneficial. There is also a case for having a front wing that rotates in a way that removes some load and tunes out understeer on slow corner entry.

'It's probably subtly different for different teams, depending on what your underlying balance is,' says Dave Robson, head of vehicle performance at Williams Racing. 'Fundamentally, we're trying to shed some front wing load in high-speed corners to help address the balance between the high-speed and low-speed corners. The other thing it allows you to do is, if you shed a decent amount of load down the straight, your legality skid height becomes higher, which allows you to lower the front ride height so the car sits lower in the low-speed corner and

Giorgio Piola / FIA



Vertical, static load testing can set some boundaries with regards to aeroelasticity, but that doesn't necessarily mean a wing that passes won't behave differently under cornering conditions

picks up downforce. And you still remain within the legality limit of the skid wear. I think that is why teams would typically try to reduce the load with speed.'

On the drawing board, F1 cars must be designed within so-called legality boxes. These virtual 3D shapes define the boundaries of the bodywork and explain why all the cars look broadly alike.

'One benefit is, for example, an increase of downforce by allowing components to be out of the legality boxes,' suggests Tombazis, who was a senior aerodynamicist at Benetton, Ferrari, McLaren and Manor before joining the FIA. 'A typical one would be the entrance of the floor. If the floor is close to the ground, it produces more downforce at very little drag increase, but the floor would then go out of the legality box. The test [with] the floor is to prevent the type of aeroelasticity that would have an increase of downforce by effectively allowing engineers to design the underbody of the car.

'The second type of aeroelasticity [concerns] drag reduction. That's what typically happens on the rear wing, when they back off at high speed but are still producing reasonable downforce in low-speed corners.

'The third [concerns] the front wing which is, currently, primarily a tuning tool between front and rear balance, and high and low speed.'

'Fundamentally, we're trying to shed some front wing load in high-speed corners to help address the balance between the high-speed and low-speed corners'

Dave Robson, head of vehicle performance at Williams Racing

In the paddock at Barcelona, most teams indicated the rulebook tweaks had minor impacts on car balance. However, some mechanical compromise was required to compensate for the loss of wing flexibility.

'We're not going to lose downforce,' says Iñaki Rueda, sporting director at Sauber. 'What we're going to have is a big headache of how to balance this car from low to high speed. This is what our race engineers are working through at the moment.'

Most teams brought performance-related updates to their front wings for the Spanish GP that also complied with the stricter flexibility rules by using stiffer constructions. This was what the FIA hoped would happen, that teams would integrate stiffer front wing construction as part of a normal car development. A smaller number, including McLaren and Alpine, trialled stiffer front wings during practice at Imola, in anticipation for the rule change coming into effect at Barcelona two races later.

'We just anticipated one wing,' says David Sanchez, executive technical director at Alpine, 'so we managed to get the data and confirm that, structurally and aerodynamically, we are happy. It was a useful exercise to get both wing specs on track and compare them in both conditions to really see how they deliver.'

McLaren, which has been at the centre of the flexi wing storm from the start, downplayed the impact of having stiffer front wings. For instance, its team principal, Andrea Stella, suggests that the effect on drag was 'in the decimals'.

'In terms of balance,' he adds, 'when you have less of an aeroelastic effect, you will have a slightly more pointy car in high speed, and slightly more understeer in low speed. Everything is so small that it's almost within the noise from the variation of one lap to the other. I don't think this would mean any change for what the race pace is, or tyre degradation. I would say drag, balance, race pace and tyre degradation are pretty much all negligible.'

Barcelona is traditionally a track that gives a good overview of which cars are strong or not, due to its variety of corner types and a long main straight. However, other tracks with more specific profiles may yet expose teams that haven't adapted as well as their rivals to the stricter tests.

Testing methods

Front and rear wing flexibility tests are carried out in the FIA's garage at a grand prix. The car's nosecone, with front wing attached, is removed from the chassis and fixed to a frame. Heavy blocks connecting to the underside of the frame's upper beam are lowered onto the upper surface of the wing and the amount of deflection is recorded. Rear wing deflection is measured with the wing still attached to the car.

These tests are good at determining how much a component flexes under vertical load, but they have obvious limitations. Chiefly, vertical load is not the only actor when an F1 car is lapping a track. Other significant variables such as yaw and wind speed cannot be accounted for in the static examinations. This makes it almost impossible for the FIA to know exactly what the teams are doing with their wings' aeroelastic properties. It can put up some barriers by defining the vertical load test requirements, but that won't catch every type of possible deflection. This is where the fun lies for the engineers working on the cars.

The FIA's Nikolas Tombazis doesn't think there will ever be 'certainty and closure' on the topic of aeroelasticity, which has flared up several times in the last 30 years

'The biggest challenge in aeroelastic tests is to try to bridge the gap between what happens in real life, when the car is running at 2-300km/h, compared to when it's static,' confirms Tombazis. 'The aerodynamic load on these components is applied on the whole surface. It's a variation of pressure which has a resultant force. But, if you apply that resultant force, the deformation you get won't be the same. The key challenge on these tests is to try to mimic real life as much as possible, knowing it's never possible to do that entirely.'

There is an added difficulty for testing the front wing. Designs vary greatly across the grid, based on how each team wants to control airflow to the underfloor and how they want to curate low-pressure areas to generate downforce.

'The biggest challenge in aeroelastic tests is to try to bridge the gap between what happens in real life, when the car is running at 2-300km/h, compared to when it's static'

Nikolas Tombazis, single seater director at the FIA

'These differences make it very difficult for us to say, this is going to be the aerodynamic test in this direction and at this point, because it would be different for different cars,' says Tombazis. 'We've observed in the past for some of these tests, there isn't a direct, perfect correlation between what you see on the camera, of which cars deflect more, and what you see statically. That is because there are such [design] differences. The differences in other parts of the car are much less pronounced. Other tests are easier to get right, but the front wing has always been a very difficult one.'

Another discrepancy between the FIA tests and real-world running is that front wings are often subjected to loads greater than the 100kg they are tested against.

There are multiple ways aeroelastic bodywork can aid an F1 car. In the modern generation, it is largely about adding load to dial out understeer in low-speed corners

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The FIA reckons the introduction of active aero in 2026 will reduce the incentive for teams to exploit aeroelasticity, although it will likely take a few races to see if this rings true

'Aerodynamic load is dissipated, [but] not point load,' notes Tombazis. 'Therefore, with the point load, you need to be careful not to cause local damage to the thing you're testing. You need to make sure it's safe enough for testing in our garage. So, there are practical limitations to approximating the real-life loads. These things for the front wing are never going to be perfect. They are the closest we have got so far, I would say.'

Ongoing matter

Much of the talk about aeroelasticity has focused on the short term, and how it might impact the current hierarchy. But what will happen in 2026, when new regulations bring cars with entirely new characteristics? DRS will disappear as an overtaking aid, but rear wing flaps will continue to open on the straights and shut through the corners as part of an active aerodynamics package, brought in to reduce drag, thereby maintaining straight-line speed in cars whose power units have more powerful electric motors but a very strict energy limit.

'I don't think it will go to bed at all,' says Tombazis of the aeroelasticity topic. 'There are some things that maybe alleviate the burden on the teams a bit. The active rear wing means the incentive to have rear wing aero elasticity will be reduced. Therefore, that is likely to mean the final tests are going to be a bit milder than [they are] currently.'

Aeroelasticity looks set to be an ongoing battleground after the current rules expire this winter. It seems the only way to nip it in the bud would be to introduce a spec front wing…[but] that would not be in the spirit of F1

The latest version of the 2026 technical regulations was published on 10 June. It includes multiple revisions to the section on bodywork flexibility, which is broken down into different car parts. The changes mainly concern the testing procedure. For example, the rulebook now states that front wing flap flexibility will be tested when the flaps are closed in what's now called 'cornering mode' (previously known as Z-mode). It also specifies that the 60N load will be applied through a 25mm rubber pad that will sit entirely on the flap surface. The amount of deflection will be measured relative to the forwardmost front wing element. As was the case in prior issues of the regulations, the front wing flap can deflect by no more than 10mm. By comparison, the front wing flap cannot flex by more than 3mm on current cars.

'That is because we wanted to give the teams a bit of a tuning device, to try to get the balance right,' suggests Tombazis. 'As it is completely new cars, and fairly difficult to get the low / high speed balance right, we may not be quite as stringent on the front wing flap aeroelasticity. But the remainder is likely to be similar to now. The regulations are going to be new, so there may be things we learn along the way and maybe have to make tougher after the first few races when we see how things are evolving.'

There has been one change made to how much a certain item of bodywork can flex. This concerns the front wing end plate, which was previously limited to 5mm of deflection under a 50N load. The test load has now been increased to 60N, while the amount of flexing has increased to 7mm. So, the amount of deflection allowed has risen by proportionally more than the load used in the FIA test.

Aeroelasticity looks set to be an ongoing battleground after the current rules expire this winter. It seems the only way to nip it in the bud would be to introduce a spec front wing; every unit built to the same specifications. However, that would not be in the spirit of F1. The game of cat and mouse between engineers at the teams and the FIA is what makes the championship so technically intriguing. Without it, the next great technical innovation in F1 may never be realised.

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Building a Legacy

How Damien Bradley transformed a £500 shopping car into the current fastest closed car on the UK hillclimb scene

By MIKE BRESLIN

While 800bhp in a club or national level racecar is impressive, it's not quite as unusual as it once was. There are a handful of cars with this level of horsepower in Time Attack, for example, as well as drag racing of course. What is more unusual is to have an 800bhp car that still looks like a regular road car, yet that's the trick Damien Bradley has pulled off with his remarkable Subaru Legacy hillclimb machine.

Bradley's Legacy is, arguably, the quickest car with a roof on it that currently competes on the ferociously competitive British hillclimb scene, even making the Top 12 Runoff against the unlimited, big-downforce single seaters when the tracks are on the damp side. By the time you read this, it will also have competed at the Pikes Peak International Hill Climb. Quite an achievement for something that started life as an old lady's shopping car.

Croydon, UK-based Bradley had always wanted a Legacy, rather than the more obvious Subaru offering, the Impreza, and there were a few good reasons for this: 'One of the biggest things was the affordability, and the fact the Legacy was never a car that would be considered boy racer-ish,' he says. 'It was under the radar, yet the platform allowed for every GC8 [first generation Impreza] modification; everything is interchangeable.'

Scooby two

The car Bradley currently campaigns on the hills is actually his second Legacy, bought after making the decision to find a lighter, two-wheel drive base model, without a sunroof. He tracked this 1992 example down in south east London and purchased it for just £500. 'It genuinely was a little old lady's car that she used for shopping,' he says with a grin.

Damien Bradley's Subaru is a far cry from the standard saloon car it started as, holding class records at nearly every British hillclimb venue

'It was under the radar, yet the platform allowed for every GC8 [first generation Impreza] modification; everything is interchangeable'

Damien Bradley, owner / driver

However, he estimates that around £150,000's worth of work has gone into the car over the past 14 years or so, but stresses this has not been a money-no-object affair. He works as a builder, and it's been a gradual process to get the now four-wheel drive machine to a point where it's been able to beat the closed car record at Shelsley Walsh.

The competitive development of the Legacy started in Time Attack, the no-holds-barred, against-the-clock, circuit-based category but, as his interest in the discipline waned, Bradley discovered hillclimbing, largely through the involvement of his friend, Steven Darley. Darley runs an Impreza on the hills and has had a big input into the development of the Legacy. After a few runs up the Shelsley course, Bradley was hooked.

While both Time Attack and hillclimbing are against the clock, the scenes are quite different, as are the cars that compete. Largely because Bradley had resisted the temptation to develop a full aero package for his car – whereas some of the Time Attack aero is very dramatic indeed – he did not have to radically alter the Legacy to fit the hillclimb regulations, which in the saloon car classes do not allow for much in the way of aero development.

'I hadn't fully investigated aerodynamics because the car worked well as it was,' says Bradley of the Legacy when it was in Time Attack spec. 'I was also on a tight budget, so I didn't have crazy aero, just a rear wing, and only a basic one I bought on eBay. I also had some removable front canards on it that were made by ABW Motorsport, who also made the wide 'arch body kit.'

The body kit was added after Bradley found the 400bhp his engine was producing at the time was too much for the semi-slicks, and then rally slicks, he was using; the car clearly needed a bigger tyre footprint.

The core of the body still remains largely original though. The a, b and c-pillars are all standard Legacy, and the roof skin has only been replaced because the car was rolled. Fore and aft of the main 'shell, though, subframes have been fitted, rather like on a British Touring Car Championship vehicle.

'Everything on the car, in terms of chassis legs, chassis pick-up points, is original,' Bradley says. 'It's been chopped at the front and chopped at the rear, but the subframes still bolt to their original mounting points. TSS fabrications make the front subframe, and it's basically a tubular steel structure, and SDM make the rear subframe.'

Peak performance

That said, there have been some recent modifications inside the bodyshell, mainly because Bradley secured an entry for Pikes Peak – an enormous achievement in itself – that meant he had to make some alterations: 'We've made some significant changes, the rollcage being one of the biggest things,' he explains. 'We needed to add two extra side bars for Pikes Peak, which run along the driver's legs, because they have worries about cars hitting boulders. Also, they wanted a different arrangement of the rollcage above my head. The original was installed in 2012 when the car was used for track days, and when the work for Pikes Peak was done by Roelands Motorsport it was discovered that the 'cage was made from ERW [electric resistance welded) tube, rather than proper motorsport-grade steel.'

Consequently, there is a full FIA / Pikes Peak-spec 'cage in the Legacy now, which certainly makes the car safer, but has also improved its performance. 'We did some testing, and I could not believe the difference in chassis rigidity, in terms of the amount of body roll and my feel for the car,' says Bradley.

The weight of the Legacy is around 1150kg, which, while not particularly light, is not bad for a steel-bodied saloon car. Besides, when you have 800bhp on tap, weight is not as much of an issue as it might be. Which neatly brings us to the heart of this project.

Boxer punch

The powerplant now in the car is a version of Subaru's legendary GCA engine, a horizontally-opposed, four-cylinder boxer. This unit is based on the EJ22, a type originally produced for the US market, but now displaces 2.35 litres, rather than the stock 2.2. It has been developed by Subaru engine wizard, Mike Latimer, and the spec includes Mahle Extreme Plus pistons, worked AVCS cylinder heads and Cosworth camshafts and inlet manifold (see p34 for more detail).

The headline act, however, has to be the turbocharger. Bradley's Legacy previously used a Garrett GT35 R turbo, which at the time helped to bring the power up to around 600bhp. 'And then we discovered AET Turbos,' says Bradley of the firm whose livery now adorns the car. 'They introduced me to Xona Rotor turbochargers, which were used mainly on big power Porsches, some of the twin-turbo Lamborghinis and other roadgoing supercar builds across the world.

The Legacy is refreshingly uncluttered when it comes to bodywork modifications, the main work in this area being the wider wheelarches, which were added when it was a Time Attack car

The rollcage has recently been uprated for the car's assault on Pikes Peak, which has both improved safety and significantly increased the car's torsional rigidity

'Everything on the car, in terms of chassis legs, chassis pick-up points, is original. It's been chopped at the front and chopped at the rear, but the subframes still bolt to their original mounting points'

Damien Bradley

They are *very* expensive units, but super efficient, with a billet core and a very efficient wheel design.

'Andy [Taylor, of AET] always dreamt of seeing one of these turbos used on a racecar. So, we put one on the Legacy, and the difference was absolutely mind blowing. It almost felt like we had switched to a normally aspirated car, it was so incredibly responsive.'

To make the car even more responsive, a Turbosmart anti-lag valve was also fitted. Lag, however, is not the only well-known problem to afflict big power turbo cars; cooling can also be an issue, though Bradley says this has not been a problem with this particular machine. In fact, he ran it with a standard production Legacy radiator until recently, mainly because UK hillclimb runs are very short. However, the cooling had to be completely revised for the attack on Pikes Peak, with a bespoke intercooler and cooling system from Allisport, because of the much

Cornering performance is optimised by three differentials that work across the car, aided by electronic torque bias and traction control

Engine is a highly modified, 2.45-litre version of a Subaru EJ22 flat four boxer. Star of the show is the ultra-efficient Xona turbo, which has helped boost power to 800bhp, with an attendant 600lb.ft of torque

longer course – equivalent to 22 runs up Shelsley Walsh in the UK – and also the thinner air at more than 4000m altitude.

Power ceiling

Amazingly, while 800bhp is surely impressive enough, this car is capable of more. 'We were running 3bar boost at Shelsley on the record run [when the car broke the existing closed car record], and we think it was probably getting close to 900bhp then,' Bradley says. 'Torque is around 600lb.ft [813Nm], and we cap it at that, just out of fear of transmission breakages. We have broken propshafts, driveshafts and things like that in the past.'

Bradley is also well aware that there's more to getting a quick time up a hill than huge numbers, and in recent years has tempered his ambitions for even more impressive power figures. 'I had a dream of achieving 1000bhp,' he admits, 'and we were pushing towards that. Maybe that's something to come in the future, but I went down a different route and really focused on the mechanical grip of the car, the handling characteristics, and also my driving. At the beginning of last season, we did the first six events at 1bar of boost, the absolute minimum power the car could produce, to see how close I could get to my records just through improving my driving. That was a real eye opener, and brought me on in leaps and bounds, especially in comparison to my approach before, which was just relying on turning up the wick to get a fair time.'

Unsurprisingly, the car runs with traction control, but this is a relatively recent development. 'We didn't run traction control for a number of years,' says Bradley. 'Paul Blamire, who mapped the car – a very intelligent guy who works for a company called EcuTek Technologies – said to me up until about three years ago, "We're not putting traction control on the car, because all you will do is lean on it." Then he enabled traction control at Wiscombe [Park] on a very wet run and, when I came back in, he pulled the data logs and said: "You're using every single bit of the traction control that was available to you."'

'I had a dream of achieving 1000bhp… but I went down a different route and really focused on the mechanical grip of the car, the handling characteristics, and also my driving'

Damien Bradley

Now, the traction control has been tuned to suit Bradley's driving style: 'We had 12 settings, and I was only using either off or up to three. Anything more than three was too intrusive. What we've done now is spread settings one to three between zero and 12. Now, I can turn it right down to the point that it's nearly off, and get a bit of feel for the tail end of the car mid-corner, before I pick up the throttle on corner exit.'

Differential equations

When it comes to those corners, of which there are many tight ones in a hillclimb course, Bradley says the car is close to neutral and, while it will oversteer or understeer if provoked, it will usually go where he wants it to go. That's largely thanks to the differentials. 'It's a very neutral, very balanced car. You can get it to understeer into a corner if you're an idiot with it but, as soon as you pick up that throttle and the diffs start to work, it will go wherever it's pointed.

'There are three differentials,' Bradley adds. 'There's a Cusco 1.5-way plated front differential, while the centre differential is an original Subaru DCCD [Driver Control Centre Differential] system, same as you'll find in the road cars; you've got a dial and a display on the dash, and you can adjust it for more front or rear bias. Then there's a 1.5-way Kaaz plated rear differential.'

It's the front unit that's proven the most difficult to get used to, says Bradley: 'It was quite a steep learning curve and, at first, I thought it was a big mistake. The car torque steered a lot more, and the diff' was really tight. I think it could probably benefit from dialling it back a tiny bit but, that said, it has bedded in now and I have learned how it works.'

The centre diff', while a factory part, is now controlled by a bespoke ECU map – also created by Blamire – that works off the throttle position and steering angle, in terms of how much it will lock, so the torque split along the car is constantly adjusting on a run.

Shift work

In a discipline that's all about fractions of seconds, quick shifts count. With this in mind, Bradley has invested in a very hi-spec Samsonas six-speed sequential gearbox, which he says has been 'completely fault free' since fitting. The paddle shift, on the other hand, has taken a little while to get right. 'When I first tried to run an electronic paddle shift system on the car, it didn't work at all,' he remembers. 'Basically, the electronic actuator didn't have the torque required to change gear on a Subaru gearbox; from a sequential perspective you need quite a lot of force to change gear on one of these.'

Since then, Bradley has found a paddle shift system more suited to the car. 'It's been in there for about a year now. It's an MME system. It has a pneumatic actuator and there's 900Nm or something of torque in the rod for the gear change. It's phenomenal, it's instantaneous, and it's super aggressive on the downshift.'

Switching to Öhlins TTX 46 four-way adjustable dampers transformed the handling of the Legacy, Bradley improving his times by over a second at most UK hillclimb venues

Helping those downshifts is an auto-blip, while there are now much shorter ratios in the gearbox, the car geared for (just!) 174mph in top at 8000rpm. Formerly, the car had a theoretical top speed of 245mph, which is clearly not the sort of velocity you would see at a UK hillclimb venue. For reference, the fastest ever top speed posted at Shelsley Walsh by a saloon car is 123mph, and that was by Bradley in this machine.

Bells and whistles

With much of the original bodyshell remaining, it's no surprise the front suspension is MacPherson struts, optimised with the best available parts. There's also a wide-track anti-roll bar on the rear and another incorporated into the subframe in the front. The real magic, though, comes with the dampers.

'When we were in Portugal [for a one-off outing in the Braga round of the FIA Hill Climb Masters] I met Russ Walton from [Öhlins agent] Mick Gardner Racing,' explains Bradley. 'He promised me half a second on each of the hills in the UK if we switched to Öhlins, and so we did. It's a TTX 46, which is four-way adjustable, with all the bells and whistles. The only thing it doesn't have is blow-off valves, because I don't tend to ride or hammer kerbs.

The fastest ever top speed posted at Shelsley Walsh by a saloon car is 123mph, and that was by Bradley in this machine

'We did a very basic set-up at MGR and I took just over two seconds out of the record at Prescott, and then over a second out of nearly every other record I hold.'

Building up relationships with suppliers like MGR is all part of the process for Bradley, and this extends to brake supplier, Alcon, which has since appointed him a brand ambassador, alongside the likes of FIA World Rally and Rallycross champion Petter Solberg.

'Originally, we ran one of Alcon's off-the-shelf Subaru front brake kits, with standard Subaru rears,' recalls Bradley. 'Then, once I tied up the deal with Alcon, we switched to a full bespoke motorsport set comprising billet six-pot front calipers and 380mm, fully floating discs, all with quick release fittings. The rear is, again, full bespoke motorsport, with R5-based four-pot calipers. Then there's the latest Alcon pedal box in the car, the first of its type. We also run a Pagid RST2 pad; they've got an amazing initial bite, which is important in hillclimbing.

'There's a Bosch Motorsport M5 ABS kit in the car, too,' Bradley adds. 'The electronics can also lock the rear differential on heavy braking, so the car out-brakes pretty much anything else on the hills, even some of the lighter single seaters.'

Avon was a previous title sponsor of the Legacy and Bradley helped develop some of its tyre compounds. He is currently still using his stock of the company's rubber, but will switch to Nova product soon

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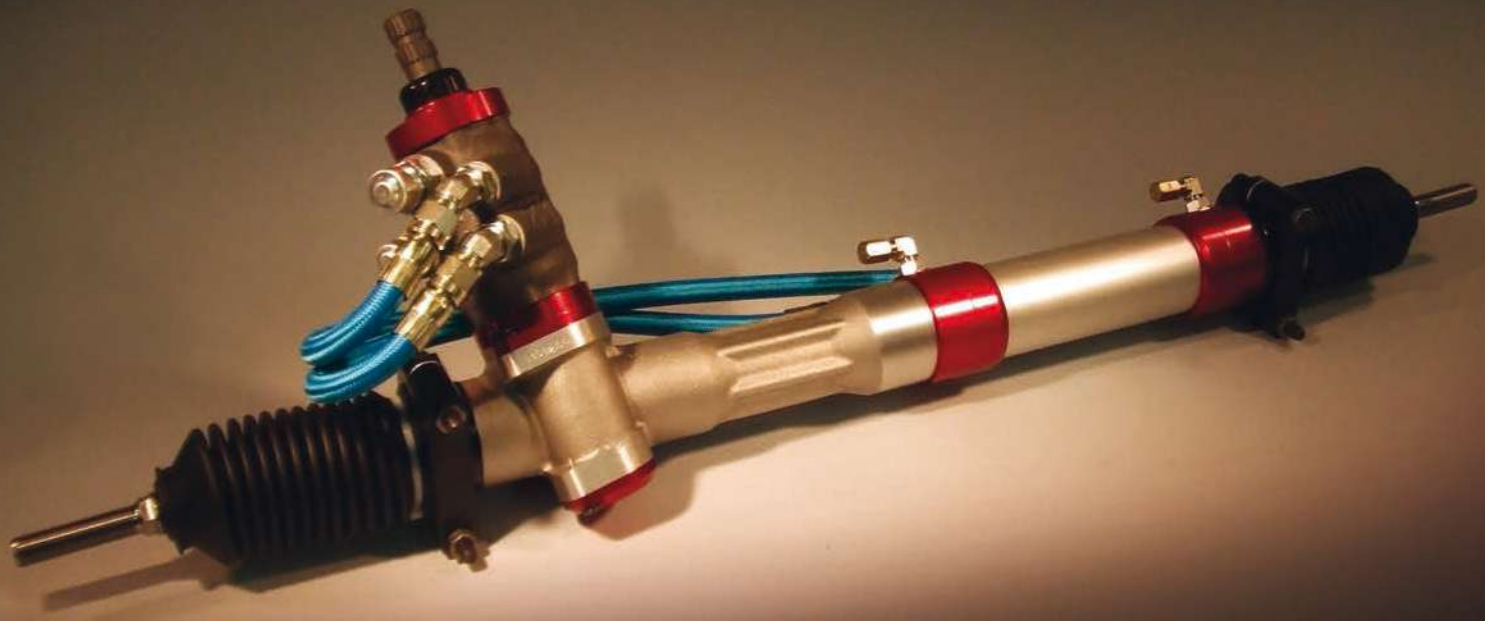

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However good the differentials, suspension and brakes are, they're of little use if the tyres cannot take advantage of it all. This has been quite an issue in top-level hillclimbing in the UK in recent times, following the demise of the Avon brand in motorsport. Bradley had a close partnership with the British tyre company – it was the car's title sponsor for a while – and he still has enough stock of its product to be going on with. He is also confident he will be able to forge a similar relationship with Nova, the new tyre manufacturer that has stepped into the breach to continue production. Incidentally, at Pikes Peak he's using the Avon 800 tyre he had a hand in developing for the longer mainland European hillclimbs.

Hi-spec hardware

By now, it will be clear that electronics play a big part in this car, and the Legacy supports a very high level of hardware and software when it comes to the sparks, including a loom that took around 400 hours to build.

'Peter Middleton at Relentless Performance made the loom, and he says it's very similar to what you would see on LMP cars,' confirms Bradley. 'There are several bulkhead connectors so, if a section of the loom is damaged, you can just twist lock off a bulkhead connector, have that section re-made, and connect it back on again – a bit like on the BTCC or WRC cars.'

The ECU is a Syvecs S12, manufactured by Life Racing, again very high end, having been designed for 12-cylinder race engines. Other electronic goodies include suspension potentiometers, a Blinkstop 12-channel wireless steering wheel with paddle shift and a Bosch Motorsport drive-by-wire conversion.

Against this technological backdrop, the one area where this car might seem somewhat lacking is the aero. This currently comprises a duck fin from an E30 BMW M3 at the rear and a modest splitter at the front, but not much else. Bradley does have plans to compete on more of the longer European hillclimbs, though, and that will probably mean the car will need some work in that area in due course.

'I can do okay in the UK on the short, complex, technical hills, but I don't believe I can do it out there on the long, flowing high-speed stuff [without aero]'

Damien Bradley

'I can't do that without aero, in my opinion. I can do okay in the UK on the short, complex, technical hills, but I don't believe I can do it out there on the long, flowing high-speed stuff,' says Bradley. 'And there's not a flat floor on the car, either, so that would need to be done, and probably a diffuser. I think you're going to see it at some point with a rear wing, certainly a flat floor, and a very discreet diffuser on the rear.'

'Discreet' is the telling word here, as Bradley still has reservations about going down the full aero route. 'It's one of the core values for me that it still looks like a Legacy, and all that might ruin the look of the car. Team Legacy is all about the Legacy, I'm all about the Legacy. I love the fact it retains its retro look and style.'

It would indeed be a shame if that identity was lost, because the USP of Bradley's Legacy is that it still looks largely like a regular road car, just one with supercar performance. On the other hand, just imagine how fast this extraordinary machine might be with a well-sorted aero package…

The car at this year's Pikes Peak International Hill Climb. Aero additions have so far remained subtle, with an unobtrusive splitter and small rear spoiler, but a flat floor and diffuser will likely be added in the future

Alcon brakes provide the car's extraordinary stopping power, while a Bosch Motorsport M5 ABS kit and electronic diff' locking also help

TECH SPEC: Subaru Legacy hillclimber

Chassis
1992 Subaru Legacy bodyshell; ABW Motorsport wide arch body kit; polycarbonate side and rear windows; Roelands Motorsport FIA / Pikes Peak-spec rollcage; TSS Fabrications tubular front subframe; SDM tubular rear subframe, SDM tubular gearbox cradle

Engine
Mike Latimer-built 2.35-litre based on Subaru EJ22 block.
Mahle Extreme Plus pistons; Carrillo CAR con rods; ACL race series bearings; RCM stopper gaskets; SMG fully worked AVCS cylinder heads; Supertech inlet and exhaust valves; Cosworth Camshafts; RCM / Tomei Vernier pulleys; Cosworth inlet manifold; eight ASNU 1350cc fuel injectors; Xona 9564S turbocharger (from AET); custom Allisport FMIC and radiator; Turbosmart FPR8 fuel pressure regulator, ALS40 anti-lag valve, OPR and WG50 wastegate; CSK titanium rear exit and side exit exhaust (depending on venue); CSK ALS Motorsport exhaust manifold

Power
800bhp; torque: 600lb.ft / 813Nm; self-imposed rev limit: 8500rpm

Transmission
Samsonas short-ratio sequential gearbox; Cusco 1.5-way front differential; MME paddle shift actuator; Exedy triple-plate clutch; Berrisford Engineering gun-drilled wide track rear driveshafts; plated Kaaz R180 rear differential; Cusco rear differential cover plate

Suspension
Öhlins TTX46 dampers; TSS Fabrications rose-jointed front lower arms; Wisefab front and rear uprights; Whiteline Motorsport-supplied wide track lateral links; rose-jointed front drop links; 24mm adjustable wide track rear anti-roll bar; steering rack bushes and wide track rear drop links

Electronics
Syvecs S12 Motorsport ECU and PDUX3B-AS by Life Racing; Relentless Performance bespoke motorsport wiring loom; Bosch Motorsport drive-by-wire conversion; Syvecs 100Hz GPS accelerometer; Aims MXS GPS dash; Blinkstop 10-channel wireless steering wheel; Antigravity ATX20 Restart battery; ECU Masters ADU7; Turbosmart boost control solenoids; Blinkstop custom motorsport keypad

Brakes
Front: Alcon Motorsport TA6 custom six-pot calipers with fully floating 380mm discs and Pagid racing pads
Rear: Alcon Motorsport R5 four-pot calipers with 330mm discs and Pagid pads.
Bosch Motorsport M5 ABS brake kit; Alcon fixed PBA875 motorsport pedal box kit; bespoke brake and clutch cylinders; HEL Performance brakes lines

Wheels and tyres
2Forge 18 x 10 ET22; Avon 046 or Avon 800 (for longer courses)

Weight
Approx. 1150kg

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These Fuelish things

Encouraged by Chevrolet general manager, Ed Cole, John Dolza and Zora Arkus-Duntov led development of a new concept for Corvette in 1957 that went on to make history

By KARL LUDVIGSEN

With hands in pockets next to a smiling Harlow Curtice of Buick is John Dolza, the Italian who brought intellectual power to the technology of General Motors

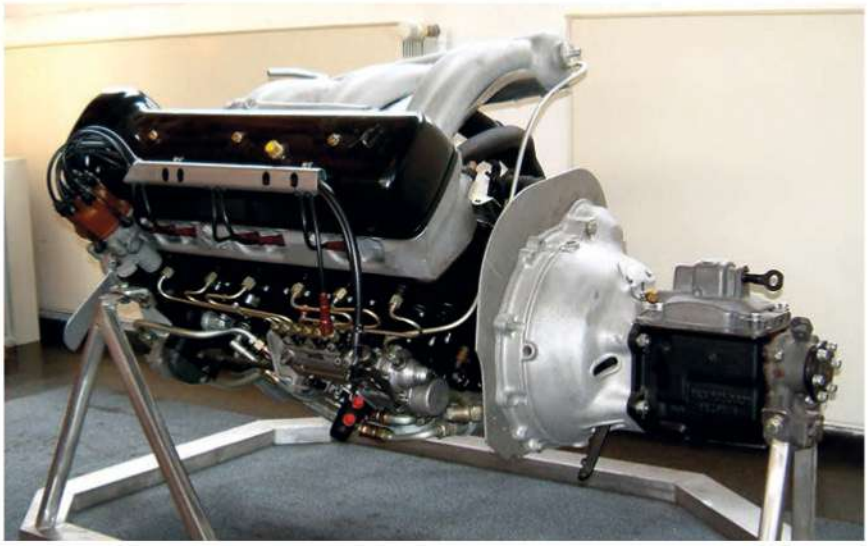
'Is fuel injection possible by Sebring?' That was the hopeful enquiry from racing driver, John Fitch, to Ed Cole, Rosey Rosenberger and Zora Arkus-Duntov on 29 February 29 1956 when the 12 Hours of Sebring race was only four weeks away. Fitch, who had enjoyed the benefits of injection at Mercedes-Benz, was eager to have it for Corvette's first big race. Cole, too, was impatient to enjoy injection's advantages, but for Sebring in '56 was overly optimistic.

As the General Motors division's chief engineer, Edward Nicholas Cole was deeply involved in planning for the new 1957 model, fielding press previews, dealer meetings and final conferences on advertising strategy. This would be the first new Chevy that would be all Cole's own, the car that would kick off his recent appointment as vice president of General Motors and, more importantly, general manager of its Chevrolet division.

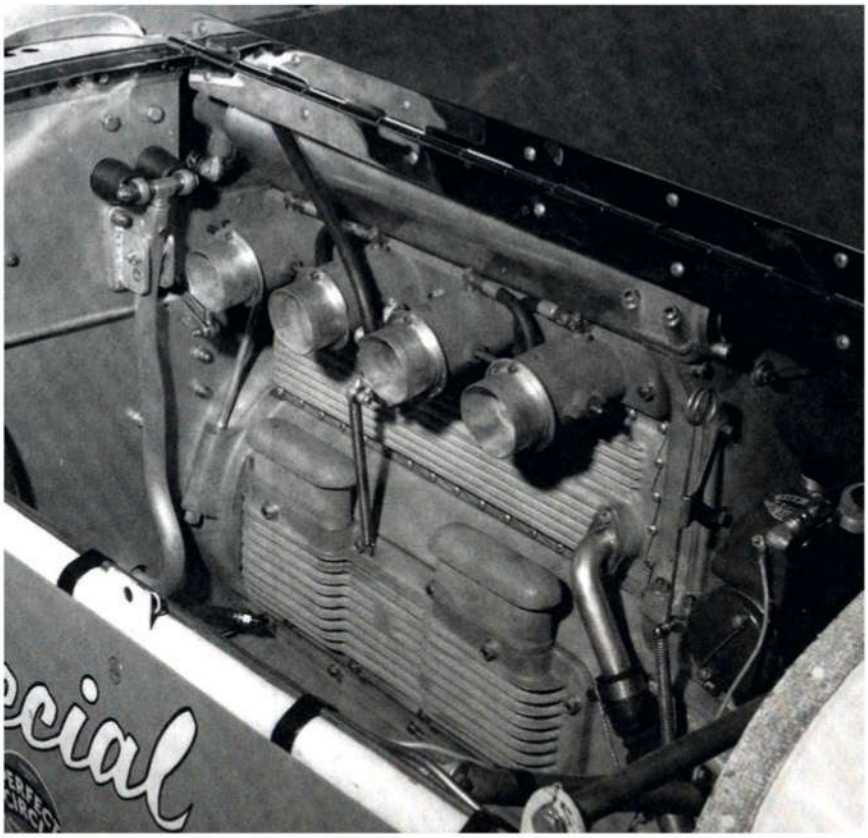
Cole felt the 1957 Chevrolet needed something extra. The stylists had delivered a fine facelift, but its basic body still dated from 1955, while rivals Ford and Plymouth were busy stacking up all-new designs. A new engine option was to be offered, using the 3-7/8in bore of the 1956 Sebring-modified Corvette to bring the V8's displacement to 283ci, but this alone was not likely to make engineering history.

For his 1957 Chevys, and especially for the sporty Corvette, Cole wanted fuel injection. The auto industry had been talking about it, and experimenting with it, for years and GM had developed its own system, though in the summer of 1956 it was not yet cleared for production. That's what Cole wanted.

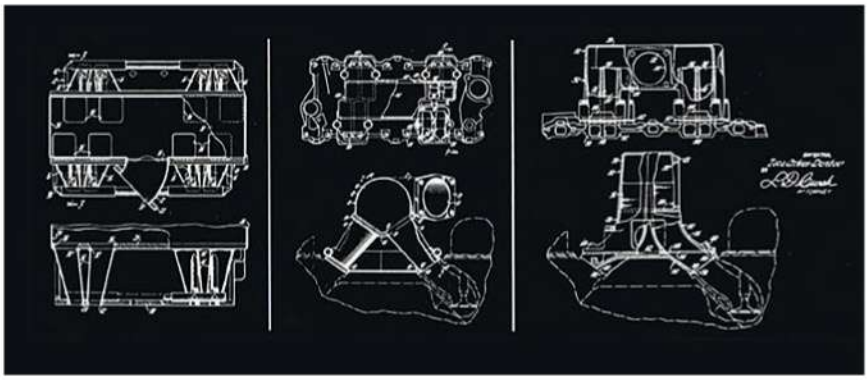
Since the early 1950s, GM's central engineering staff had been working on various devices capable of delivering carefully metered amounts of fuel directly to each



For the Mercedes-Benz 300SL's inline six of 1954, Bosch provided the fuel injection, an inline fuel pump and pipework to the individual cylinders. GM bought two of the German marvels to evaluate the engineering prowess



Stuart Hilborn's constant flow fuel injection system had the merit of great simplicity, metering fuel through a distributor to the respective cylinders of this Drake Offenhauser that appeared at Indy in 1949



Engineering drawings show the so-called 'sturdy dog' configuration of the early injection manifold units built and tested by John Dolza and Zora Arkus-Duntov in 1956

'A fuel system capable of correcting even 50 per cent of the average carburettor deficiencies may produce a 10 per cent improvement in fuel economy that would ultimately result in substantial savings to the customer'

Giovanni 'John' Dolza

cylinder in exact proportion to the incoming air under all operating conditions. The reason being carburettors, and their associated long manifolds, had long been considered unsatisfactory and inefficient.

The Dolza division

At GM, research on injection was headed by Giovanni 'John' Dolza. Born in Turin, Italy in 1902, Dolza earned an engineering doctorate from that city's Technical Institute before arriving in America in the early 1920s. Dolza found his way to Detroit and, in 1927, to GM's Buick division, where his special talents were recognised. The first of Dolza's many patents were filed in January 1929, for a combined air cleaner and silencer, followed four months later by a new design of carburettor.

When Buick's chief engineer, Charles Chayne, took over the corporation's engineering department, he immediately put Dolza in charge of power development. A master of sophisticated control systems, Dolza was the ideal man to take up the fuel injection challenge.

Enlightening the Society of Automobile Engineers (SAE) about GM's system in 1957, Dolza cited some of its potential advantages over carburetion: 'A fuel system capable of correcting even 50 per cent of the average carburettor deficiencies may produce a 10 per cent improvement in fuel economy that would ultimately result in substantial savings to the customer. The possibility of an exhaust free from hydrocarbons and a fuel system free from evaporation would greatly help in an important phase of reducing air pollution.' These were appealing attributes long before emission control became an issue in America.

Reaching an advanced experimental stage in the 1930s, fuel injection made fast progress during the Second World War for use in aero engines. Germany's Bosch pioneered the use of timed injection in two-stroke engines

produced by Gutbrod in 1953, and in 1954 Mercedes-Benz had it on its four-stroke 300SL, as well as its new racecars. By that time, GM was also investigating the technology.

Injection at Indy

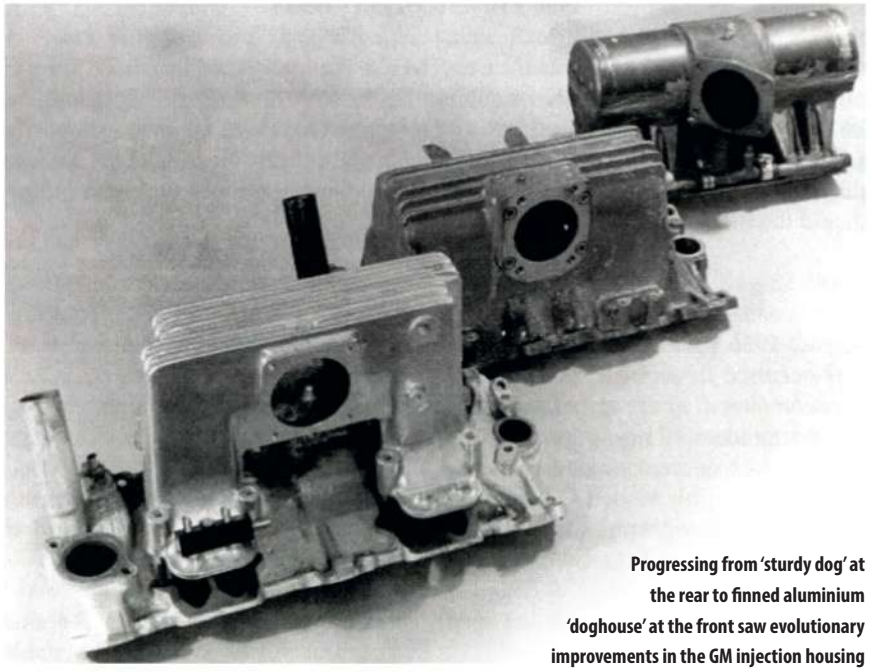
GM engineer, Kenneth Kayser, credits Harley Earl with taking an interest in injection as early as 1949, when a constant-flow system developed by hot rodders, Stuart Hilborn and Jim Travers, was used in qualifying at Indianapolis on the Offenhauser four in the Howard Keck Special. By 1952, 26 of the 33 starters in the 500-mile race were using Hilborn injection. Earl urged GM chief, Harlow 'Red' Curtice, to start work on such a system and, in 1951, he asked for injection as an adjunct to Buick's new V8 engine. Evaluation began on two different systems that could lead to distinctive designs for GM's highly competitive divisions.

Meanwhile, engineers on Dolza's team included Raymond Haefner, Max Holmfeld, Stephen Kalmar, Stanley Mick, George Ransom and John Zimmerman. Assisting was Adelbert 'Al' Kolbe, detail designer of the Chevrolet V8. Joining them was an engineer on loan from Chevrolet, where you'll recall Cole was eager to corner the GM market on fuel injection for his new V8. So far, Cadillac had been the lead division, with Buick waiting in the wings. Cole's nominee was Zora Arkus-Duntov: 'Ed Cole called me one day and said, "Listen, if I didn't have my job to do, I'd give my right arm to be working on fuel injection." And I think he was being truthful.'

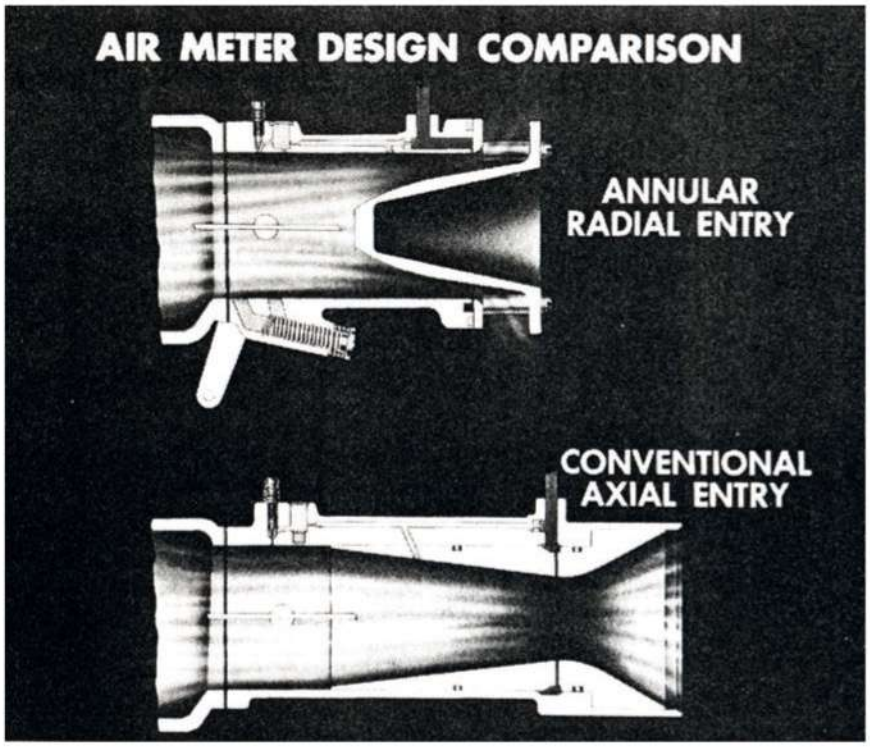
And so, in early 1955, injection became Duntov's chief assignment. His subsequent escapades at Pikes Peak and Daytona were extracurricular, partly charged to his fuel injection development budget, though, as the whole programme was top secret, no official accounting was required.

Following the examples of successful aircraft fuel injection systems, Dolza began working on fuel metering controls that were sensitive to the speed of the engine and the density of the air being inhaled. He sought to compare these two parameters to decide how much fuel to deliver at any given point. Such a system worked well enough, but promised to be expensive. This was certainly the case with the elaborate Bosch injection fitted to the two Mercedes-Benz 300SLs that GM bought for evaluation.

As he confided in a memo to Cole, Duntov was worried about weaknesses in the prototypes that could affect reliability. He suggested measuring the mass of air entering the engine directly, instead of deriving it from the two signals Dolza was using. He mentioned a Holley carburettor used by Ford that provided full vacuum control of its distributor advance, controlled from several pressure taps in its venturi and above its throttle plate. Through Cole, this recommendation found its way to Dolza.



Progressing from 'sturdy dog' at the rear to finned aluminium 'doghouse' at the front saw evolutionary improvements in the GM injection housing



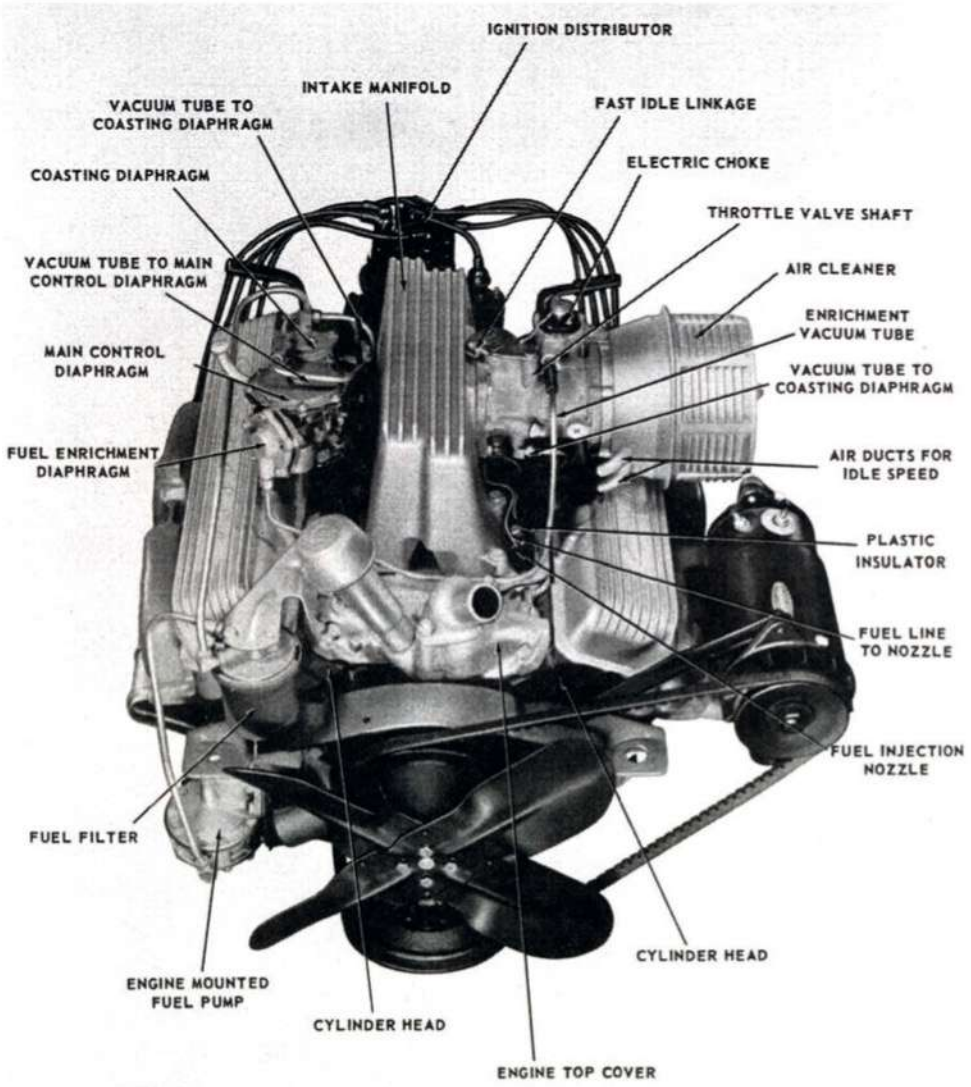
Compared to the conventional venturi design for the measurement of incoming airflow, shown at bottom, GM's engineers adopted an annular air entry that was more compact, but no less efficient

'John Dolza is a splendid man,' Duntov recalled with admiration, 'brilliant and clear thinking. I can spare no words to say how powerful this man is intellectually.'

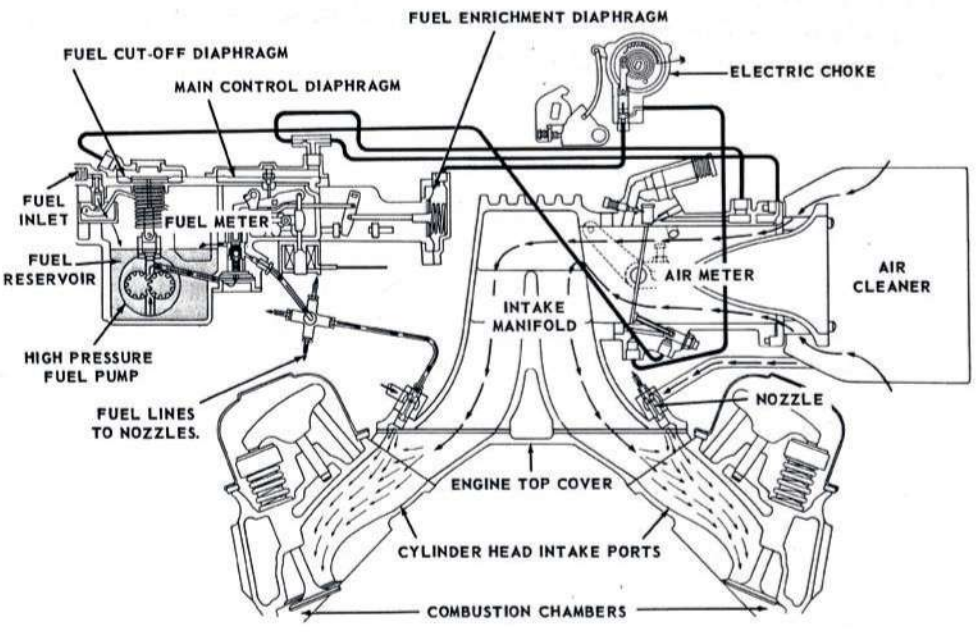
In a matter of days, Dolza had come up with a completely new metering method for a constant flow injection system. Its operation was based on a venturi, through which all incoming engine air passed, taps from which sent vacuum readings to a fuel metering unit. 'Dolza had worked this all out mathematically,' wrote engineer, Dave McLellan, of the

'John Dolza is a splendid man, brilliant and clear thinking. I can spare no words to say how powerful this man is intellectually'

Zora Arkus-Duntov



Callouts identify the features of the new for 1957 GM-Rochester fuel injection system. The height of the 'doghouse' intake manifold, the lower part of which also serves as the central valley cover, encloses passages that give an induction air ram effect



Individual passages carry the incoming air, with fuel added via injectors just at the point where the manifold joins the intake ports

'The difference in performance indicated that fuel injection brought out the work potential in an engine which otherwise existed in the test graphs only. We valued this quality since it meant more work per engine pound and dollar'

Zora Arkus-Duntov

system's controls, 'ultimately relating air velocity to fuel flow. The equation that expressed the constant relationship between venturi pressure drop and fuel flow was reproduced in the mechanical analogue system by forces transmitted through the control arm lever. This was its essence as a typical analogue control system in the days before digital electronics.'

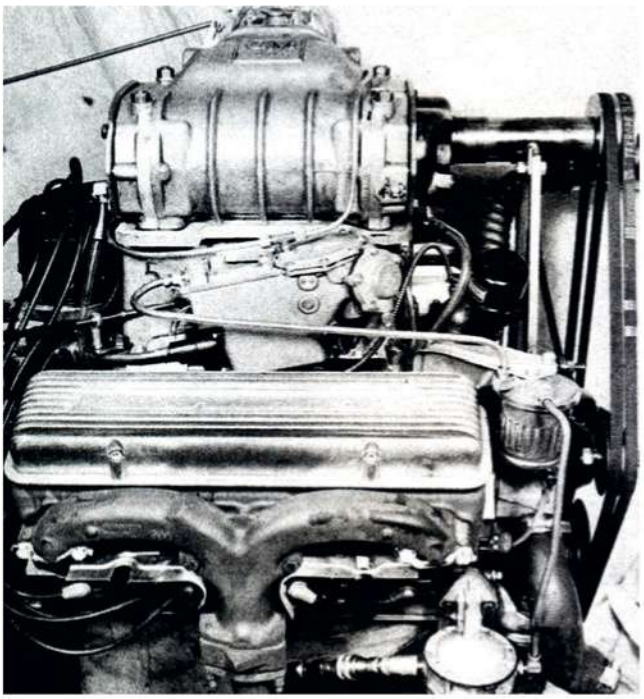
Early tests

First tests on Chevrolet engines in 1955 used normal intake manifolds fitted with injection nozzles and an inlet venturi in place of a carburettor. This allowed direct comparison with the carburetted version. Dynamometer tests showed virtually no difference between the two in power output. Though such avenues as ram-tuned intakes and higher compression ratios hadn't yet been explored, this seemed an inauspicious beginning for Chevrolet, which was hoping to exploit injection to extract extra power from its V8.

However, the Dolza-Duntov system had a surprise up its sleeve. Tests of injection vs carburetion were run in a prototype 1956 Chevy, which accelerated to 60mph, and higher, nine per cent faster than the carburetted example. 'The spectacular increase in vehicle performance with otherwise identical dynamometer power,' reported Duntov, 'can be attributed to the ability of fuel injection to maintain the best power mixture throughout the transition. The difference in performance indicated that fuel injection brought out the work potential in an engine which otherwise existed in test graphs only. We valued this quality since it meant more work per engine pound and dollar.'

Similar results were shown by an improved injection system feeding a twin-carburettor manifold, and so work began to find out what size and length of ram pipe to each cylinder would give the best results on the new, larger, 1957 Corvette engine with a Duntov-designed camshaft. With this established, the ram pipes were united by a fore-and-aft plenum chamber fed by the metering venturi.

Strenuous rig testing was necessary to bring the GM injection to full readiness against the pressure of time for the launch of Chevrolet's 1957 models



In an attempt to extract additional power, the Chevrolet team tried attaching a GMC Roots-type compressor to the fuel injection system. In the end, it was not exploited

Late in the programme, Duntov had his own small team on the project, including Fred Frincke, Dean Bedford jnr and technician, Louis L 'Lou' Cuttitta.

Dogs and doghouses

The first complete dedicated injection manifold was fabricated in sheet steel. Its barrel-shaped body and tapering 'legs' to the inlet ports won it the nickname of 'sturdy dog'. An intermediate, cast aluminium manifold that served as the V8's central valley cover was made in some numbers for the first extensive vehicle tests. Covering the valley was also a function of the final injection manifold design, which was made in two parts, a finned upper and a lower section, to slow the transmission of heat to the injection nozzles, as well as to make the engines easier to manufacture and install. This one was nicknamed the 'doghouse' and its final design credited to Duntov, who insisted on a handsome-looking piece that would reflect the effort that had gone into its development.

Air entered the doghouse through a circular paper air cleaner and an annular venturi on its left side. Attached to the right-hand side of the doghouse was a fuel float chamber, fed by a regular mechanical fuel pump. Inside the chamber was a gear-type pump driven by a flexible cable from the same shaft that turned the ignition distributor. Its output was delivered to what its inventors called a metering cavity.

'Some of the fuel delivered to the metering cavity flows directly to the eight continuous spray nozzles,' said a Dolza and Duntov SAE paper. 'The remainder of the fuel flows through the spill ports back to the float chamber. The amount of fuel spill (and, consequently, the fuel delivered to the injectors) is regulated by the spill plunger.'

The latter was moved by a lever, whose position was changed by a diaphragm that read the pressure in the air inlet venturi. Air bled into each of the individual injection nozzles provided the conditions needed for idling, while various auxiliary systems provided for cold and hot starts, acceleration and closed throttle overrun.

These were the characteristics of the constant-flow injection system developed by GM's engineering staff, in cooperation with AC spark plug division, with support from Chevrolet. It was not yet injection for the Corvette, though, or even for General Motors. Nor did it have a potential manufacturer, although GM's Rochester Products Division in New York, long the manufacturer's producer of carburettors, was expressing interest.

Constant competition

In-house competition came from a timed injection system with a pump and distributor that delivered spurts of fuel to an engine's inlet ports. Early in 1956, the decision, which went all the way to Red Curtice, put this constant flow system on track for production. Simpler and less costly, it was preferred to the timed alternative, whose reliability was still to be proved. Effective 1 February 1956, Rochester started planning its manufacture, overseen by Donald Dibble Stoltman.

With fuel injection still in turbulent transition, John Fitch's plaintive query for Sebring fell on deaf ears. Chevy's chances of seeing injection in its 1957 production cars received a painful setback in April 1956, when

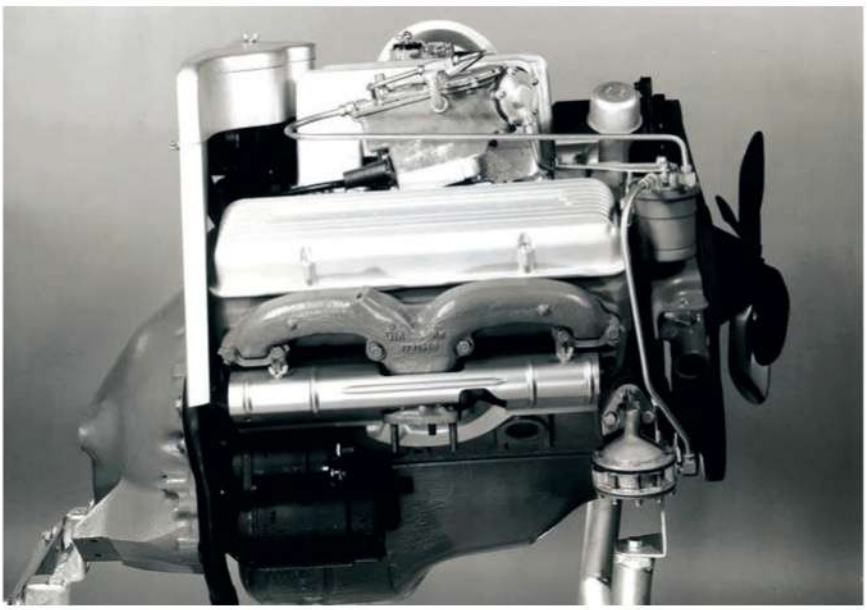
'On the dyno it worked. In a race version, loosened and cheated up a little, we got a real one horsepower per cubic inch'

Smokey Yunick

Duntov broke his back in an accident at GM's proving ground. With the days slipping away, both at Rochester and Chevrolet, for the adaptation of injection to production models, something had to give. It turned out to favour the Corvette. Harry Barr and Duntov recommended to Cole that injection be introduced first on the company's low-volume sports car, and only later phased in for the regular sedans. Although apparently 'incensed' by this turn of events, Cole approved, provided there was 'only a short temporary delay for passenger cars.'

Determined that his stock car racers would not be denied the benefits of fuel injection, Cole launched a back-up plan. It relied on the skill and dependability of Smokey Yunick, then in his second year of supporting Chevrolet's stock car racing programme with Mauri Rose. 'GM sent the injector stuff down,' Yunick later related, 'and paid to have a 12ft fence installed around my race shop. They even paid to have it guarded 24 hours a day, seven days a week with Wackenhut guards.

'Along with the fuel-injection set up, Cole said, "I'll send an engineer down to help you." Ralph Johnson was his name. He was perfect. He worked his ass off, drank like a fish, chased



As readied for installation in a 1957 Corvette, the fuel injected Chevy V8 was a compact and powerful package

The automobile engineering world was eager to discover how GM's engineers had used logic and ingenuity to create a fuel injection system of apparently remarkable simplicity

women like a wild man and we both hated the 'god-damned injector.' But, for the amazing salary of $1000 a month, we did it. Well, on the dyno it worked. In a race version, loosened and cheated up a little, we got a real one horsepower per cubic inch.' However, on track, it failed to make the car go any faster.

Midnight run

Puzzled, Yunick and driver, Paul Goldsmith, were running at 120mph one dark night on a Florida highway when Smokey opened a door in the firewall to relieve under-bonnet air pressure. A blast of air knocked him into the rear of the car and the car's speed jumped rapidly to 140. 'Problem solved,' said Yunick. 'The under-hood pressure drove the injector dead rich. Turns out I had my head up my ass for a month. The injector totally operated on pressure differential, and I knew that.'

Final approval for the fuel injection system's production came not at the 11th hour, but the 12th, with the first units being built under virtual laboratory conditions at Rochester Products Division. Ellsworth Alfred Kehoe also worked on the injection under chief engineer, Elmer Olsen. The original inlet venturi was replaced by a radial-entry annular venturi, designed by Don Stoltman, which was easier to make and

Chevrolet took full advantage of its engineering development to set the Corvette ahead of its regular production saloons. Of 6339 Corvettes sold in the 1957 model year, 1040 were 'fuelies', at a hefty surcharge of $484.20

'No one at Chevrolet or Rochester was apparently honest and / or daring enough to admit to Ed Cole that the Ramjet Fuel Injection System needed a few more months of gestation!'

Kenneth Kayser

more compact, but the company's engineers struggled with the new technology.

'Rochester,' wrote Kenneth Kayser, 'was unprepared for such a large undertaking as fuel injection, but covered up their shortcomings so well that Zora could not get injection units to develop the application properly to the Corvette V8, much less passenger cars, too. In May of 1956, there were only three Chevrolet Engineering fuel injection test cars,' And of those, only one was a Corvette, a 1956 model, serial number 5950. 'Harry Barr was forced to get involved and negotiate with Rochester.'

Eventually, Rochester agreed to release six prototype fuel injection systems, for which it charged $2500 apiece. Some must have gone to Yunick and Johnson in Daytona, while another was installed in one of the 1956 racing Corvettes for testing by Mauri Rose and Dick Thompson. Problems included poor idling, hard starting when hot, misfires, piston failures from both detonation and cracking in Duntov-cammed engines and, astonishingly, cutting out on bends – just the kind of fault that fuel injection was supposed to eradicate.

Fuel percolation in the manifold passages was still hampering test engines assembled in mid-August. By the end of that month, however, following a company-wide blitz, the injector's design was considered frozen so that production could be scheduled. 'No one at Chevrolet or Rochester,' thought Kenneth Kayser, 'was apparently honest and / or daring enough to admit to Ed Cole that the Ramjet Fuel Injection System needed a few more months of gestation!'

Proud of what had been achieved by the team of which he was a member, Duntov contacted his friends at Porsche in autumn 1957 to suggest it consider developing a version of the GM injection for its own purposes, under licence from GM. In his reply of 4 October, the company's engineering chief, Klaus von Rücker, said Porsche had found through experience that 'developments at too great a distance are heavily handicapped,' and that it planned to see what European injection makers had to offer. Germany's Bosch was, and would remain, a feisty rival in the field of fuel injection development.

Jonathan Bachman / Getty Images

Bolt action

A deep dive into the advanced telemetric data sharing system used in NASCAR

By BOZI TATAREVIC

NASCAR is unique in many ways, not least the fact that it gives all competitors access to a limited set of telemetric data.

This feature debuted as part of the NASCAR Team Analytics application that was introduced in in 2019, which featured data collected by SportsMedia Technology (SMT) that teams could subscribe to. This was introduced in response to various teams using external audio and video analysis to try and reverse engineer telemetry information from their competitors. Separately, NASCAR collected timing, scoring and pit stop information, which was available to competitors via various data streams, and a few years ago the organising body decided to improve all of these elements and combine them under a new platform.

A new pit lane officiating system, developed in conjunction with Bolt6, uses 4K cameras to track the positioning of crew members and equipment throughout a race

NASCAR started development of the Event Racing Data Platform (ERDP) in 2023 and put it into production the following year. The core functionality of the ERDP is to act as a publishing engine for telemetry and optical tracking data. ERDP initially collected data from SMT's tracking system, alongside a new optical tracking system from Bolt6, along with telemetry from the McLaren Applied ECU and associated sensors in the car. The Bolt6 optical tracking system eventually replaced the functionality of SMT's system, although data is still being displayed through the SMT data viewer, albeit supplied by data from ERDP.

To find out the latest developments, *Racecar* spoke with Dane Vander Haar, managing director of electronic systems and competition technology at NASCAR. Vander Haar is no stranger to telemetry and data acquisition as he started his career at Pi Research, supporting data systems in IndyCar and NASCAR, before moving to Joe Gibbs Racing (JGR) where he had a mixture of work ranging from data acquisition to building and running dyno facilities. He eventually departed JGR to join McLaren Applied, where he worked on code development for the NASCAR ECU and digital dash, alongside special projects such as Formula 1 MGU and inverter development. He joined NASCAR in 2019.

Bolt from the blue

According to Vander Haar, NASCAR decided to make the move to the Bolt6 system because its 4K video capture and positioning is more precise than a simpler, GPS-based system. The optical tracking system feeds positional and metric data to the ERDP for distribution and positional information and is processed and updated every 20 milliseconds.

Bolt6 is a sports officiating technology company that was founded in 2021 by former members of Hawk-Eye Innovations, a familiar name to readers of the optical scanning article in 2024's *Stockcar Engineering*.

The optical tracking system feeds positional and metric data to the Event Racing Data Platform for distribution and positional information and is processed and updated every 20 milliseconds

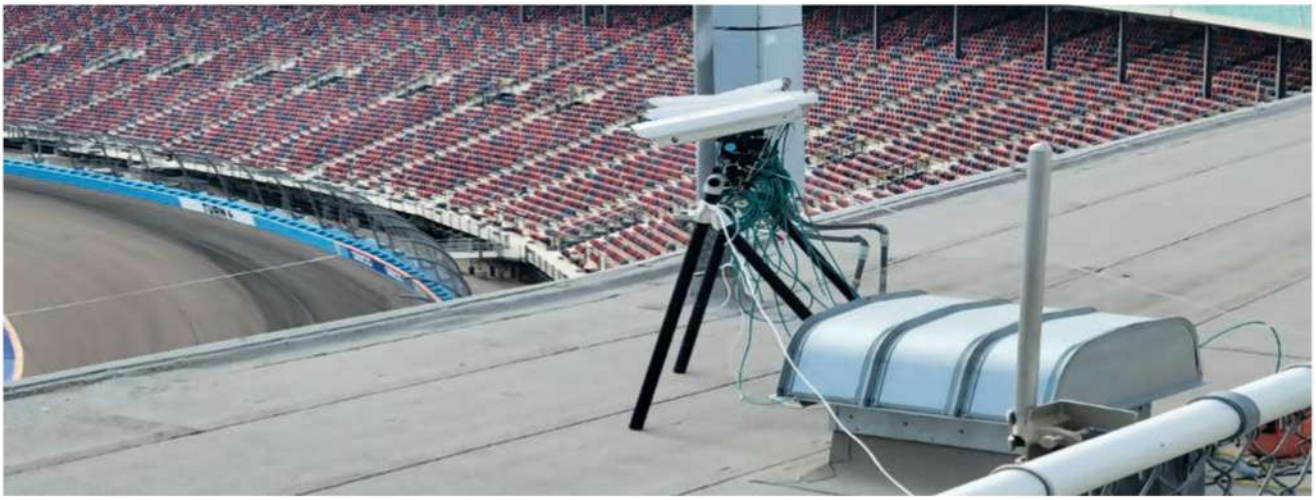
Bolt6 was the technical partner for the optical tracking system development at NASCAR and used its expertise in object identification, motion tracking and position triangulation to develop the software that runs the system. In addition to the on-track optical tracking, NASCAR also partnered with Bolt6 to improve its pit road officiating system, which runs on top.

The optical tracking system is based on 4K cameras with PTZ (pan, tilt and zoom) lenses of various focal lengths. These are connected to local network equipment at each track with a fibre optic cable that eventually leads to a central server, which transmits all the data to the Amazon AWS cloud where the processing is completed.

The networking equipment and cameras travel from track to track during the NASCAR Cup Series season, although some tracks now have permanent fibre runs ready for connection once the equipment arrives prior to a race weekend. The set-up team typically arrives two days ahead of any track activity to install the cameras and network equipment. Since this is a fully cloud-based system, the cameras can be focused and calibrated remotely.

Enhanced data

Optical tracking is not the only element of the ERDP. It is also able to track telemetric data from each car's ECU, the incident data acquisition system (IDAS), transponder-based



The 4K video and camera optical tracking technology now used by NASCAR is said to be more reliable and positionally precise than the organisation's previous GPS-based system

ERDP data is also used by a variety of other stakeholders as it populates information on NASCAR's website and mobile app, alongside elements of the TV broadcast

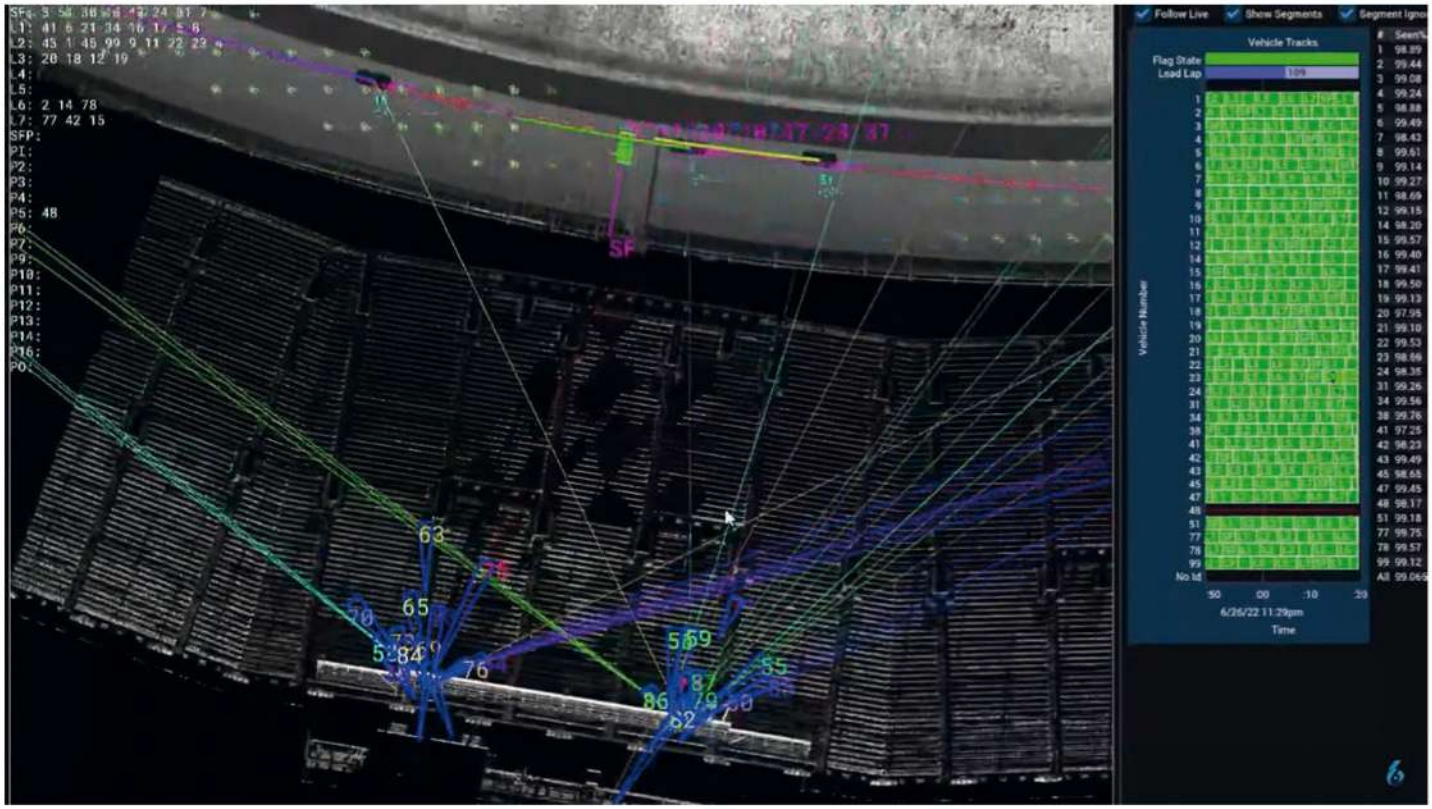
The optical tracking system's cameras are connected to a local network at each track with fibre optic cables

timing and scoring data and pit road officiating data. Data collected from the McLaren Applied ECU, ranging from driver inputs to temperatures and pressures, is sent from each car in the form of CAN messages through a telemetry radio and digested by ERDP. The system was built with the ability to expand and collect data from any other control or measurement systems that might be introduced at a later date and is currently limited only by the agreement that a small set of data point categories is to be shared. Although nothing is planned for the immediate future, the system is capable of collecting data points from systems relating to engine control, torque measurement and hybrid systems.

Approved data

Each team and OEM is supplied with a software token from NASCAR that is validated by the ERDP to generate the approved data points for a specific user. ERDP data is also used by a variety of other stakeholders as it populates information on NASCAR's website and mobile app, alongside elements of the TV broadcast. The ERDP was designed to be able to supply race data to a variety of end point users.

Teams can view speed, rpm, throttle and brake traces, along with pit road officiating data and optical tracking positional data through the SMT viewer application after it is transmitted from the ERDP. The new pit road officiating system is a development of the optical tracking system as the 4K cameras allow NASCAR to precisely track the positioning of crew members and equipment as they perform a pit stop.



Map showing data points measured by the cameras during a car stop in a pit box. As the system also tracks the position of the crew, it automatically flags pit stop infractions to the organising body

The information is then sent to a central server, which transmits the data to the Amazon AWS cloud for processing

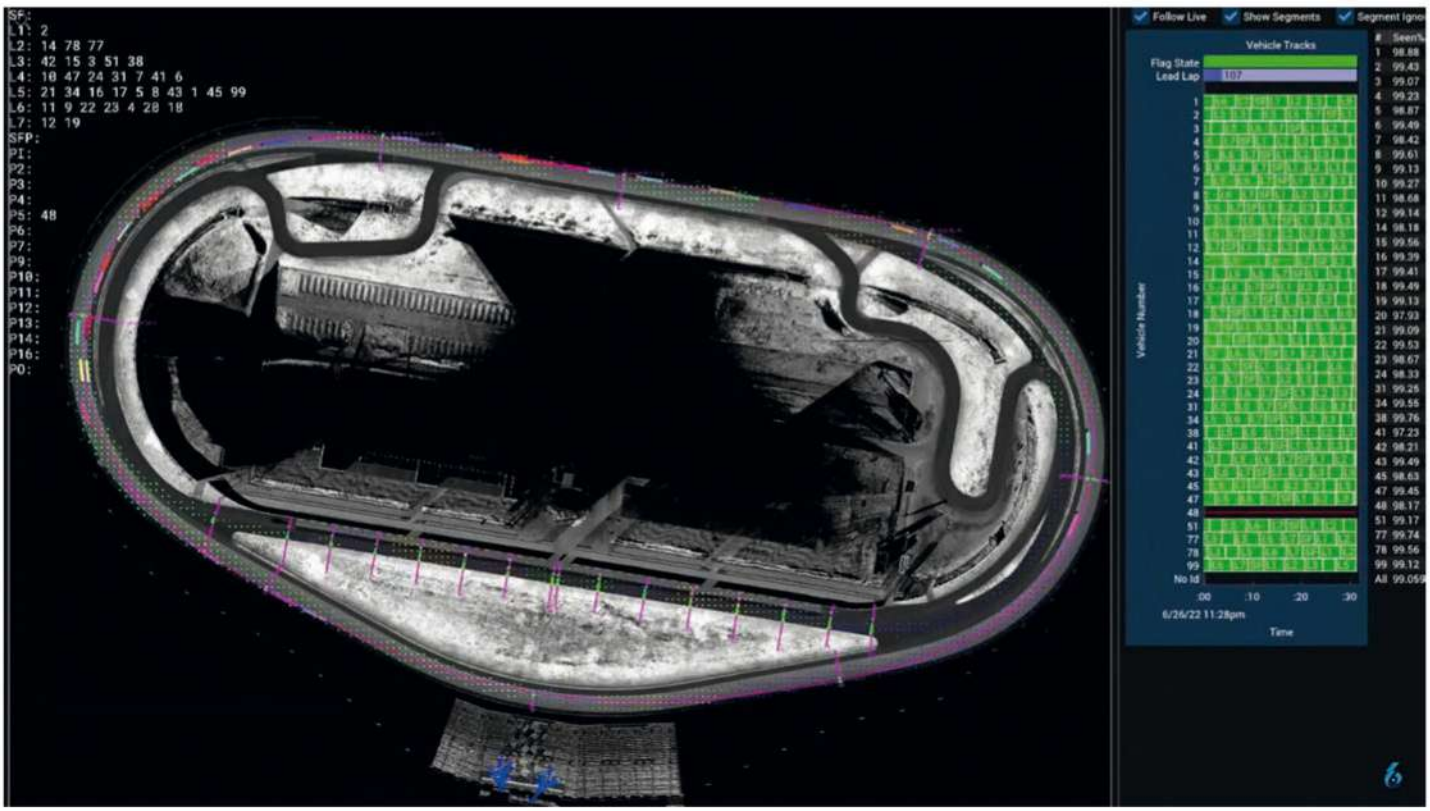
Teams can view speed, rpm, throttle and brake traces, along with pit road officiating data and optical tracking positional data through the SMT viewer application

The system is therefore automatically able to flag pit stop infractions, such as cars being outside their boxes, or too many crew members working on a car, along with providing metrics such as overall pit stop time and when the car is jacked up and dropped. The ERDP also pulls data from the incident data acquisition system (IDAS) in order to verify motion for things like pit stops, as each team is required to carry a motion pack for the IDAS that contains an accelerometer and gyro. These sensors allow quick correlation of when a car has been jacked up or dropped, in order to track when a pit stop has been started or completed.

Marelli Motorsport supplies the motion pack, which mounts inside the cabin near the left leg of the driver and serves a primary purpose of recording data during on-track incidents. The motion pack works in conjunction with the IDAS recorder mounted in the centre of the cabin and the high-speed camera mounted just above the dashboard. Meanwhile, a cockpit environmental sensor mounted near the propshaft tunnel provides information on items like temperature in the cabin. The system is completed with a GPS antenna mounted inside the rear window above the fuel cell.

Message broker

The back end of the system makes use of a NATS (Neural Autonomic Transport System) message broker, which collects data and delivers it as JSON (JavaScript Object Notation) messages. Access to the message broker is available through a cloud link for most, but there is also a trackside link available to those on the local network.



As well as being used by the teams and OEMS to assist in car set-up and strategy, data from the optical system is used by broadcast and NASCAR series applications to improve the fan experience

The networking equipment and cameras travel from track to track during the season, although some have now invested in permanent fibre runs ready for immediate connection on a race weekend

Each message contains an individual data point from a vehicle and is time stamped. The McLaren Applied TAG-400N ECU is currently configured with six data point outputs that include engine speed in rpm, steering in degrees, throttle position percentage, brake pressure in PSI, gear position and a general vehicle health diagnostic data point. The IDAS module is configured to transmit an accelerometer data point in *g* and a gyro data point in degrees per second.

The optical tracking system transmits two separate feeds. A low-latency feed at 350ms and a high-latency feed at 1000ms. The low-latency feed provides data quickly, but at a trade-off that sees around 10 per cent more breaks and jumps in tracking compared to the high-latency feed. The latter provides higher tracking accuracy and uses more video frames and a longer processing time to determine the position of the car. Applications that build visualisations are the typical end point for the high-latency feed.

Heartbeat package

The ERDP also transmits a variety of timing, scoring and environmental data. The basis of the data set is the heartbeat package, which contains identifiers like the series and race ID, along with basics like flag state and lap counters. The line crossing package monitors loop data on track as vehicles pass over it with their transponders. Timing data is transmitted in a related package and monitors items such as lap time and lap differential, as well as vehicle status and whether it is active on track or in the garage. Environmental variables such as track temperature are transmitted in degrees, along with a longitude and latitude for the sensor position on track.

Optical tracking of pit stops centres around monitoring infractions, which are then confirmed by an official, but can also offer a variety of information to the team regarding pit stop efficiency. Timing is tracked in granularity, ranging from total duration on pit road to the entry and exit time from the pit box. Individual crew member and vehicle movement is also tracked, so timing for the jack, and how long a car stays up for each side is also collected, along with driver response time from when the car is dropped until they take off.

The NASCAR official website and mobile app have also been similarly updated to offer a more data-rich timing and scoring feed

The optical system also tracks each corner and has individual data points for each tyre so it can count the number of tyres changed. Likewise, fuel is tracked based on the number of fuel containers that are ascribed to the car during an event. Any unusual circumstances are also recorded with data points for adjustments and body repairs being completed on the car.

Much of this information will be used by teams and OEMs to create calculations for car set-up and strategy, in conjunction with their internal data, but the optical tracking has also made its way to broadcast and series applications. Broadcasters have already deployed augmented reality elements like car pointers, which show a more precise location of a car during aerial coverage, collected through a data stream from NASCAR to SMT. The NASCAR official website and mobile app have also been similarly updated to offer a more data-rich timing and scoring feed that includes an aerial map showing a representation of where each car is located on track.

The platform has already seen over a dozen updates since its debut as NASCAR leverages more of the data to provide further insight to competitors and fans alike.

The NASCAR optical tracking system transmits two separate feeds – a low latency one and a high latency one. The former provides quick, accurate data on car position to the organisers, while the latter is primarily used by applications that value its higher frame rate to build visualisations and more fan-orientated content

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Information superhighway

Like the human body, the modern racecar supports an intricate system of sensors, controllers and actuators working in perfect harmony

By JAHEE CAMPBELL-BRENNAN

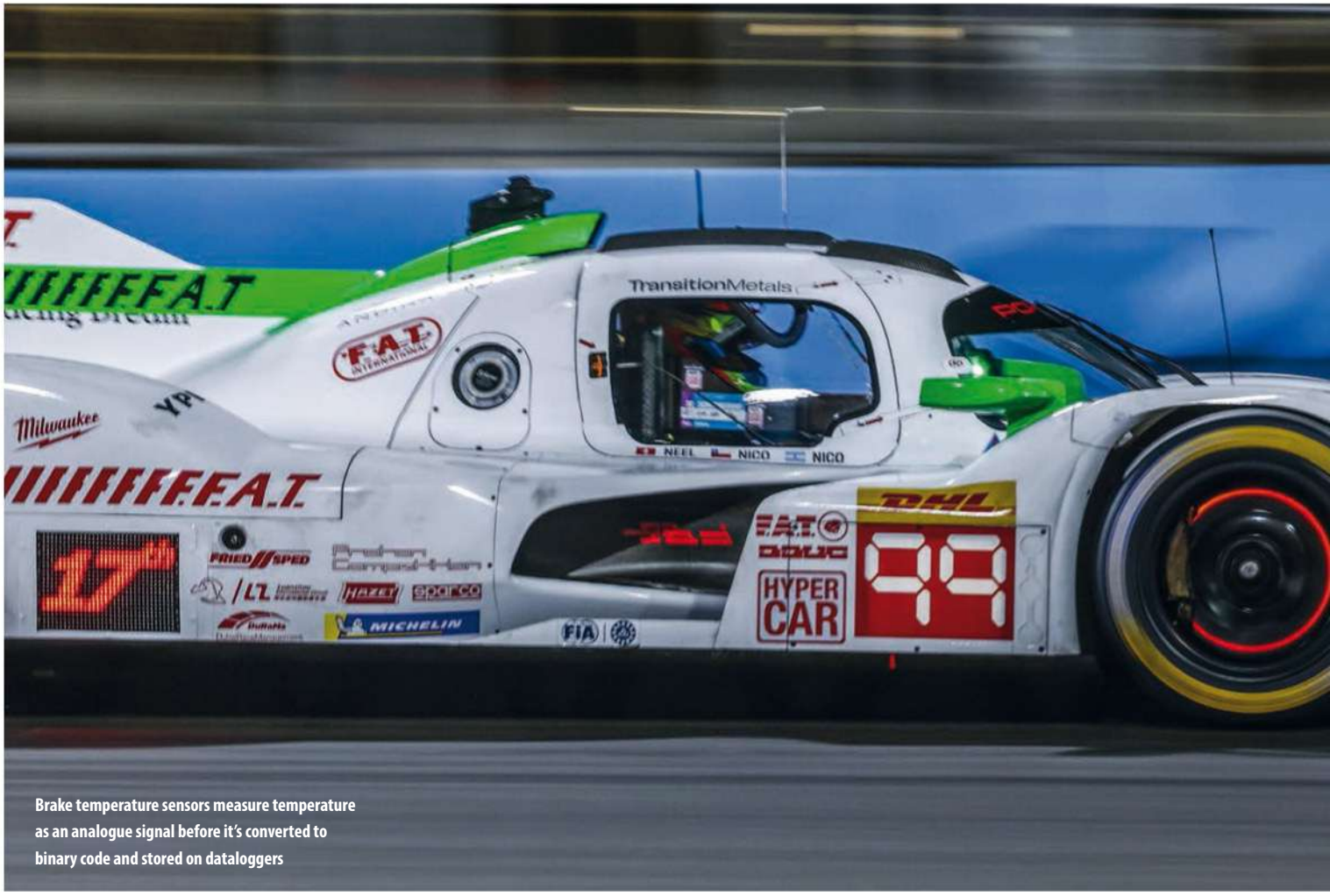
The autonomic nervous system is a silent, vigilant network of communication lines running throughout our bodies. With sensory neurons in every muscle, organ and joint detecting changes in pressure, temperature, chemistry and movement, our bodies sense our current state thousands of times every second as electrical signals are sent through nerve fibres to the spinal cord. There, control decisions are made and responses sent back out to regulate the body's systems via hormones, action potentials and neurotransmitters.

This continuous loop of sensing, interpretation and reaction happens thousands of times every second. It's completely unconscious, yet critical to life. Our nervous system is distributed, responsive and highly resilient, maintaining balance while constantly adjusting to internal and external demands. It keeps the body breathing, the heart beating and the temperature stable, all without conscious intervention. It's incredible.

What's fascinating is that a remarkably similar architecture exists in the modern racecar; an engineered nervous system of sensors, controllers and actuators working (ideally) in perfect harmony.

Sensors are a critical part of a racecar, both from the perspective of reliability and vehicle health. They measure pressure, temperature and parameters such as knock in an engine, as well as performance-related parameters of forces via load cells, position, voltage and acceleration, all in real time. These sensors act like the car's sensory neurons.

Porsche Newsroom



Brake temperature sensors measure temperature as an analogue signal before it's converted to binary code and stored on dataloggers

Just as in the human body, these sensors work with electrical signals, measuring a difference in electrical potential as a corresponding change of state.

Analogue systems

Analogue sensors are supplied with an input voltage, usually at 5V, and in turn generate an output voltage proportional to the pressure, temperature or position being measured. 5V is the standard sensor voltage because it offers a stable, low-noise power supply that balances compatibility with controllers, provides sufficient signal resolution for sensors, and strong signal-to-noise ratio to manage the effects of electrical interference.

In the world of computers, however, data must be stored as bits – digital information. So all analogue signals are eventually converted and stored digitally, but exactly where the analogue signal is converted to a digital one is crucial in ensuring the signal gets to its destination intact and without being altered by electrical interference.

The electrical environment in a racecar is extremely harsh in the context of signal transmission. High levels of EMI (electromagnetic interference) generated by components such as the ignition system, electrical pumps and fuel injectors cause havoc in the form of signal distortions, loss of data and, in extreme cases, even physical damage to a system (see box out on p62).

'It takes a lot of effort to reduce EMI to acceptable levels. Shielding, grounding, filtering, it all has to be designed in'

Stefan Weber, head of low voltage architecture at Bosch Motorsport

With the point-to-point approach required by an all-analogue sensor network, there must be a dedicated wire for each switch, sensor and control unit. However, wiring is bulky, heavy and hard to manage so, as system complexity increases, diagnostics and fault tracing become nearly impossible.

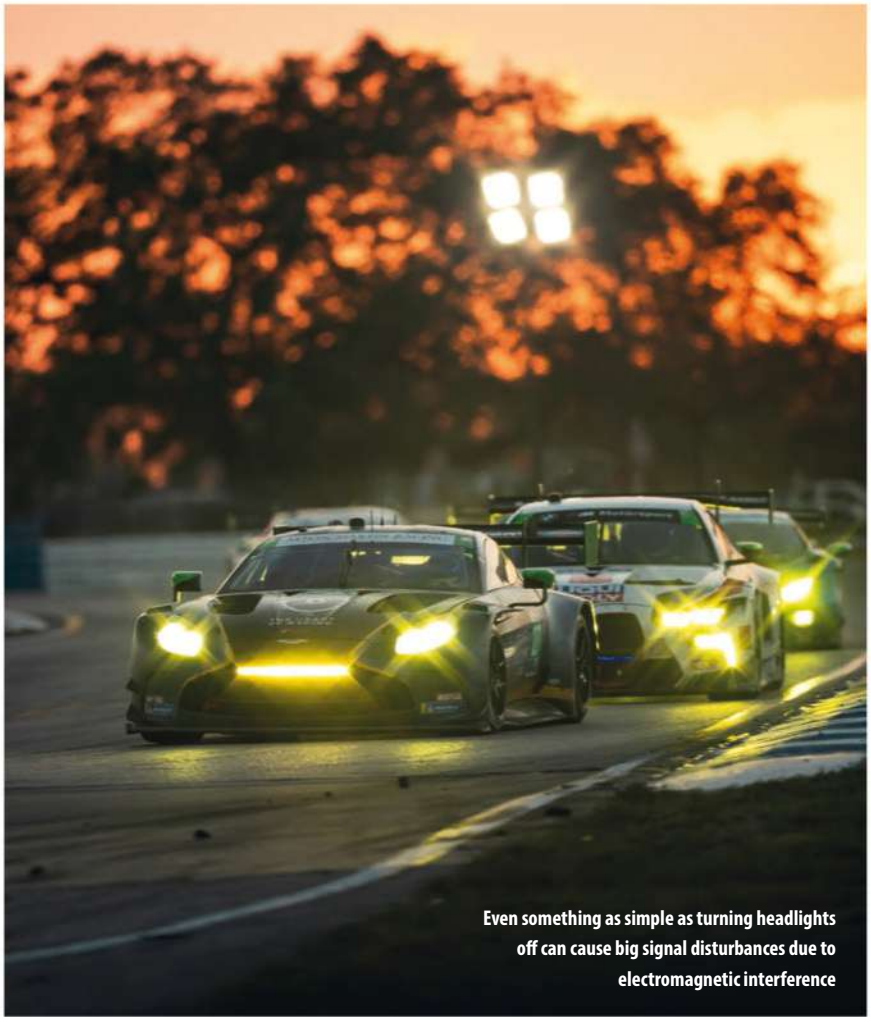
In addition to this, the EMI generated around a vehicle makes it extremely difficult to ensure the signal reaches the controller without distortion and misinterpretation, even with shielding in place.

'Even something like turning off the headlights can create huge EMI disturbance. It's not just ignition or injectors that cause the issue, it's anything with fast switching,' explains Stefan Weber, head of low voltage architecture at Bosch Motorsport. 'It takes a lot of effort to reduce EMI to acceptable levels. Shielding, grounding, filtering, it all has to be designed in.'

To manage this complexity, an increasing number of sensors have become 'digital'. The sensing element is still analogue, but the analogue signal from the sensor is converted to binary format in very close proximity to the sensing unit. Converting at source like this has the advantage of allowing the signal to be filtered or conditioned but, most importantly, digital signals are more resistant to interference.

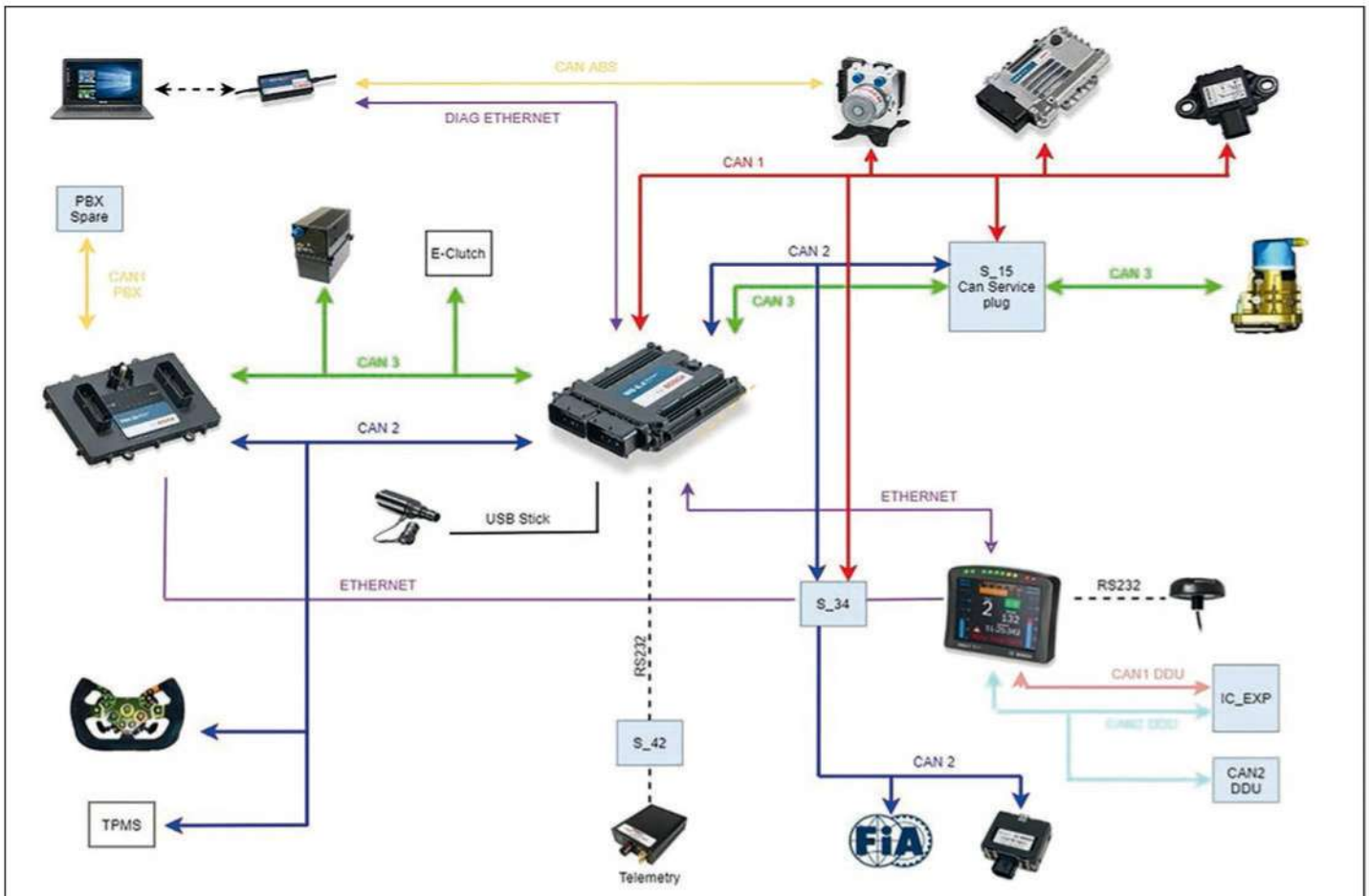
'EMI is actually a huge problem in a racecar,' exclaims Karl Klöss, senior engineer for high voltage systems at Bosch Motorsport. 'The reason why it doesn't appear so problematic is because the systems are designed in a way that they already have implemented shielding, with good filters in the components. But actually, you have hundreds of amps, very high levels of current, and if they're switched on and off rapidly, you *will* have EM emissions.'

This challenge is precisely what the CAN (Controller Area Network) was designed to solve. Continuing our analogy with the human body, the CAN system, which was introduced to racing around the 1980s, acts



Aston Martin Racing

Even something as simple as turning headlights off can cause big signal disturbances due to electromagnetic interference



Lamborghini

Racecars have seperate CAN buses to manage the requirements of different sub-systems and accommodate bandwidth requirements, as shown by this schematic of a GT3 car

like the spinal cord and brain stem of the body, coordinating responses and distributing commands.

Twisted sisters

Prior to this development, analogue, point-to-point wiring was used throughout the vehicle. The key difference between the two is the use of a shared digital network. In CAN systems, devices all connect to the same two-wire network, which is called a bus. Devices broadcast their data, and any ECU or module that needs it can listen, respond or act. These lines are arranged in what's called a twisted pair, a double-helix wrapping of the two wires. This ensures both wires are equally exposed to interference from surrounding systems, preserving the symmetry needed for clean differential signalling.

'If the electrical disturbance affects both wires equally, the differential signal remains clean. That's why the twisted pair is so important,' confirms Weber. 'Even the number of twists per metre is defined. If you get it wrong, one wire sees more exposure than the other and that can corrupt the signal. It's simple in principle, but the implementation has to be exact.'

The fundamental elements of the CAN network are built around differential signalling to transmit data. Instead of using a singular voltage and ground, it uses two wires – the CAN high line (CAN_H), and the CAN low line (CAN_L).

The CAN system, which was introduced to racing around the 1980s, acts like the spinal cord and brain stem of the body, coordinating responses and distributing commands

These CAN wires are energised to 2.5V by default, while to transmit data the CAN_H and CAN_L lines are simultaneously driven in opposite directions to 3.5 and 1.5V respectively. Measuring the difference in the voltage of both the CAN_H and CAN_L line is the key to differential signalling. The system is naturally resilient to interference. If a surge or spike is induced by EMI, both voltages shift together, yet their difference remains constant. This allows the signal to be read cleanly, with the disturbance effectively cancelled out.

The twisted pairs are terminated at each end with a 120Ω (ohm) resistor, which is a key element to the integrity of the bus. The resistors act like an energy sink to absorb the signal energy and prevent the signal from bouncing back up the line, causing false and implausible information to be received.

Network nodes

Different devices such as actuators, sensors and controllers on the network are identified as 'nodes', which tap off the signal via short communication stubs from the main loop. All nodes have access to all the information on the bus and can either act as a silent observer or a participant, by sending its own messages.

Take the throttle system as an example. When the driver presses the pedal, a position sensor measures the movement and outputs an analogue voltage. This signal is converted to digital and passed to the ECU via the CAN network. The ECU cross references this input against engine speed, load, traction conditions and fuel maps. Then, it commands an electronic throttle actuator to open or close with precision. Rotary potentiometers in the throttle body then verify that position, completing the loop.

This process happens dozens of times per second; so quickly and smoothly that the driver experiences only seamless response and control, unaware of the complex dance of inputs, decisions and outputs occurring beneath their right foot.

Wavey Dynamics

The damper potentiometer (thin blue rod next to the spring) is a crucial element of racecar performance development

The de-centralised nature of CAN architecture brings flexibility, fault tolerance and speed, making real-time control across the whole vehicle elegantly scalable.

A system journey

Let's reinforce this concept by exploring the functionality of a CAN network by focusing on one part of a system, following the information journey from sensor to data logger.

A style of linear potentiometer we in racecar engineering call a damper pot measures damper displacement and allows us, as engineers, to monitor damper position. We can then manipulate that to find wheel position and understand parameters such as ride height and the speed of wheel movement in compression and rebound.

This raw positional data can also feed into more advanced frequency domain analyses, such as PSD (Power Spectral Density) plots, to uncover natural frequencies of the tyre / wheel system and guide damping decisions. It's fundament to racecar instrumentation. To understand the journey of the signal, we begin at the raw sensor output. The damper pot is an analogue sensor, which converts the linear motion of the wheel movement into a variable electrical signal. It's essentially a resistor with a sliding contact called a wiper that, when supplied with a standard 5V input voltage, gives an output voltage of varying magnitude between 5V and 0V, depending on how much of the resistor is between the supply and the ground. At 0V output, the potentiometer would be fully extended, with the voltage exposed to the maximum length of the resistor.

After the damper pot generates a proportional output voltage, the next step is to convert this signal into digital form so it can be used by the car's control systems and data logger. To do this, the output is sent to an ADC (analogue to digital converter) where this processing step is performed with some circuitry. In digital sensors, the ADC will be located within, or in very close proximity to, the sensor unit.

Most motorsport logging systems operate in 12-bit binary format, which gives a possible total of 4096 discrete sensor values. Plenty of resolution for a damper stroke of, say, 120mm.

From the ADC, this binary value is output to a microcontroller, where logic can be applied to the value for the purposes of diagnosis, signal filtering or sensor calibration. Once the signal is digitised and logic checked, it must be sent to the network.

The next stage in the pipeline is the CAN controller, which is another device usually integrated into the same circuitry as the ADC. The function of the CAN controller is to package up the binary value it receives into a CAN frame, which is the packet of data to be

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Whether or not running a hybrid system, huge amounts of safety critical data is being sent around today's racecars, and robust communication strategy with CAN is essential

sent into the CAN bus, containing not only the sensor value, but all of the metadata required to identify the value. So, what the message is, who it is from and how to verify it. The CAN frame also indicates the priority of the message, which we'll discover the importance of shortly.

'The general metadata is stuff like how long is my data frame? You also have a message counter to track how many messages a particular node has sent, and then you have a checksum to verify the frame is correct and proper, and not corrupted,' explains Weber.

'There's already a checksum in the CAN protocol,' continues Klöss, 'but in some systems, like hybrid or drive-by-wire, we'll add another inside the data payload. That gives us a second layer of error detection and acts as further verification that the data is not being manipulated by teams to fool the regulating bodies. For critical data, such as torque requests in a hybrid system, this can be a safety issue if key features are bypassed.'

CAN 2.0

This kind of structure in a CAN frame is all standardised in the CAN 2.0 protocol, which is widely used in motorsport systems.

Think of the CAN bus as an information highway. Each destination along this highway is a node – be it an ECU, dashboard display, gearbox controller or power distribution module (PDM). Any node on the bus can broadcast or listen to messages, and each node can respond to messages as required. Like any highway, congestion can be an occurrence, and this has to be carefully managed to ensure the right messages are given the appropriate priority.

Think of the CAN bus as an information highway… Like any highway, congestion can be an occurrence, and this has to be carefully managed to ensure the right messages are given the appropriate priority

This management is known as CAN arbitration, and is the process by which all the nodes on a particular bus decide who can transmit data when more than one message is attempted to be sent at once. The message priority is included in the CAN ID. If you have a low CAN ID the priority is high, and *vice versa*.

'A time-critical signal, such as ignition at high rpm, is a totally different story to something like a temperature sensor in terms of the priority in the CAN bus,' adds Florian Giura, who works with braking systems such as ABS at Bosch Motorsport. 'A temperature change from 80.1 to 80.2degC will not change in two milliseconds, and is not critical to the operation of the car, so is given lower priority.'

Klöss continues: 'If you have a lot of participants on one CAN with high priority, which means low IDs, you could run into the situation that maybe a lower-priority message with a high ID doesn't come through at all, or very rarely. For this reason, you have to be quite precise with your CAN architecture and separate your key functionalities into different buses intelligently.'

A typical racecar such as a GT3 will therefore have multiple CAN buses. Aside from being a great way of managing CAN arbitration and priority to ensure particular signals don't get drowned out, this also gives opportunity to manage failures.

Assigning a group or nodes to a certain CAN bus is sometimes a matter of physical proximity. For example, the engine and gearbox may have a dedicated CAN line. A hybrid system would also have its own, and usually the organising body, such as the FIA, will have its own private CAN for monitoring systems associated with regulatory compliance.

Failure strategy

Occasionally, there can be software failures within nodes on the bus, in which the bus can be crowded by a constant stream of nonsense messages. This prevents important messages from being read and can crash the system. Therefore, grouping nodes that are critical to the operation of the car onto common buses, and non-critical nodes onto their own independent bus, is a common strategy to manage this.

A typical motorsport CAN bus operates with what's called a baud rate, which is the metric used to quantify its data transfer rate. One baud is usually equal to one bit, though there are exceptions to this.

Regardless of the overall architecture, data enters the CAN bus via a transceiver, which turns the CAN frame into a voltage and sends it out onto the main CAN bus. Each time a voltage differential is set between the CAN_H and CAN_L lines, a bit is logged. This is called a dominant bit. For the humble damper pot

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Racecars frequently operate in inhospitable environments, yet data must still be reliably transmitted between the various systems onboard, regardless of the conditions

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in our example here, this happens around 200 times per second, though for other systems this number can be substantially higher.

Common CAN buses in a motorsport context operate at 1Mbps, or one megabaud, which is equal to one million bits of information. The CAN bus is driven dominant at a rate of 1,000,000Hz.

Grouping nodes intelligently is also a strategy used to manage data bandwidth. As with any data transmission, there is a limit to how much can flow in a given timeframe.

'First of all, we need to take into consideration the available bandwidth on a CAN bus. This is the first separating factor. To me, I always consider what functionalities I have when designing an architecture,' notes Weber. 'Generally, everything regarding the engine can be separated into one bus, for example. You'd also put everything concerning a hybrid system on one bus for safety reasons.'

Final destination

The final destination for all this information, including our damper pot signal, is the data logger. This acts as a central hub that captures, organises and stores every signal transmitted across the vehicle's CAN network. Once the data is logged, it becomes accessible for detailed analysis, enabling engineers to trace issues, refine performance and extract insights that influence real-time decisions and long-term development. In essence, the logger doesn't just collect numbers, it preserves the story of the car's behaviour across the lap, helping us, as trackside engineers, to start the next session more informed and better prepared.

The CAN network is the foundation of modern racecar operation… It doesn't just carry data, it carries intent

The CAN network is the foundation of modern racecar operation. It links sensors, controllers and actuators together into a coordinated system capable of interpreting and responding to the vehicle's dynamic state in real time. It doesn't just carry data, it carries intent. Without it, there is no synchrony between systems, no reliable control logic and no data from which to develop performance.

As performance targets become tighter and reliability more critical, the ability to sense, communicate and respond with extreme precision becomes even more crucial.

Just like the human nervous system, the CAN network works tirelessly in the background, coordinating, responding and maintaining balance. It doesn't make the car fast by itself but, without it, coordinating the technology around modern racecars would be impossible. It's the living thread that ties the whole machine together.

Electricity creates magnetism

Every time current flows through a wire, it generates a magnetic field. When this current changes rapidly eg starting, stopping or switching direction, the magnetic field also changes. These fluctuations can either radiate electromagnetic waves into surrounding systems or induce unwanted voltages in nearby cables or circuits.

This is especially severe in inductive components like coils, solenoids and motors. When switched off, they dump stored magnetic energy back into the system, which appears as a sharp voltage spike, a whip crack of electrical noise.

In a racecar filled with high-frequency switching components such as ignition, power electronics, injectors and fans, these magnetic fields are inescapable. Without careful system design and shielding, they can corrupt signals, crash ECUs or cause mysterious, frustrating, intermittent failures. This potential for electronic chaos was a key driver behind the adoption of digital bus systems, chiefly the Controller Area Network (CAN).

BMW Motorsport

While there are many variables in a data network, one thing is for certain, the requirement for bandwidth only ever increases with the development of technology

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Machine head

Five years ago, Josh Valman planned to do a stock restoration on a 1960's Alfa Romeo GTV. That morphed into this exquisitely engineered hillclimb machine

By LAWRENCE BUTCHER

Though by no means an afterthought, the body style is not the focus of attention here, all the work so far in this one-off project has gone into the chassis and powertrain development

There are projects and then there are *projects*. Josh Valman's AB850 hillclimb car falls into the latter category. Before we go any further, it is worth noting that Valman has never built a racecar before, which makes his first effort all the more astounding.

'It was 2020 – we all know what that means – and I was keeping myself entertained,' he muses. 'It was supposed to just be a car restoration, but then I thought, let's build a chassis, and then it became let's design every bolt and go to town. It's a bit silly really.'

The car in question will ultimately have a silhouette body loosely based on a 1960's Alfa Romeo GTV and run in the FIA European Hill Climb Championship. Valman says his inspiration was an Alfa 4C currently competing in the series, equipped with a Judd V8. 'I thought, okay, let's do the classic version of that. We'll go as close to silly Formula 1-style stuff as we can, but keep it sensible. And then it's got way out of hand.'

Even more intriguingly, Valman's background is not motorsport, though he has been involved in manufacturing and engineering his entire life, working with production machining equipment and processes. His love of engineering came at a young age, via competing in the legendary televised competition, *Robot Wars*. For the past 10 years, he has dabbled in motorsport engineering, to the extent that 'dabbling' has become a full-time occupation, and he recently opened a dedicated premises in west London, UK. His main area of expertise is engines, and current projects for customers include developing a hydrogen-fuelled ICE and a bespoke V6 of his own creation.

Modular build

Valman explains that he approached the project in a modular fashion, taking on the main areas – powertrain, chassis, suspension – one at a time. 'I've been in CAD for 20 years and I knew a bit about engines, so I started with the engine package. Initially, I was working with John Hartley, who makes the Hayabusa V8s. I got some CAD from him and started building out the package. Then I designed and built the drivetrain off the back of that, and then the chassis, before moving on to learn everything I could about suspension, then designing it.'

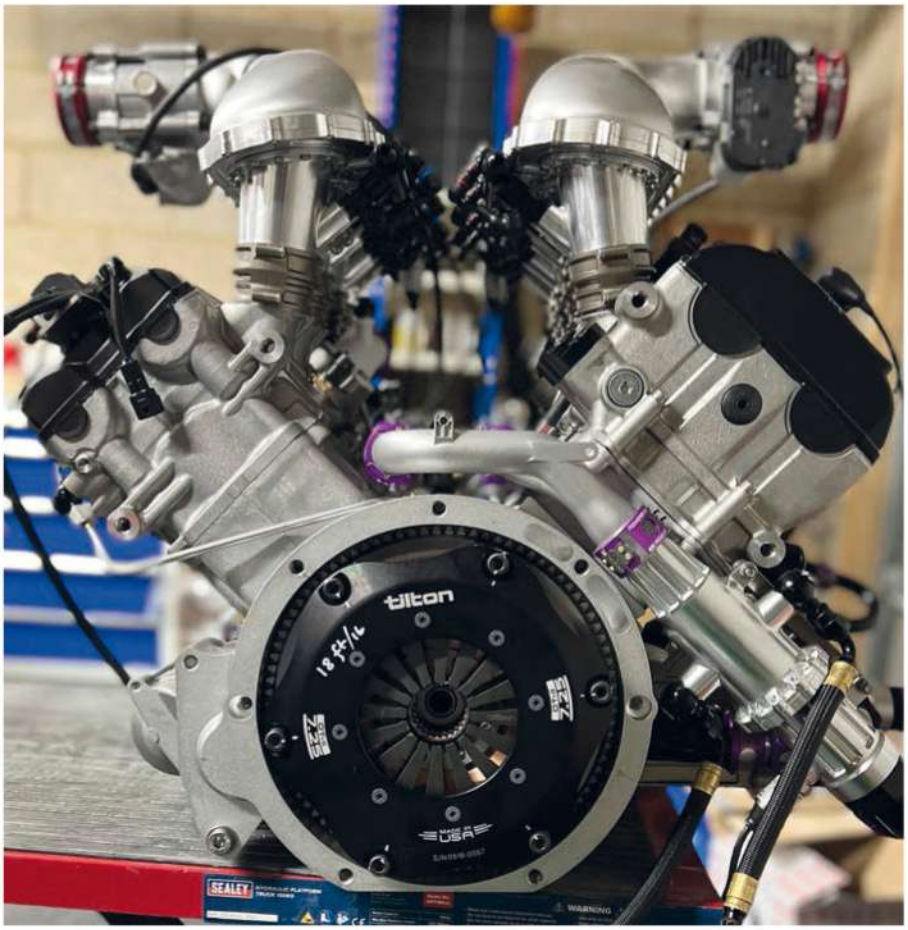
'We'll go as close to silly Formula 1-style stuff as we can, but keep it sensible. And then it's got way out of hand'

Josh Valman, owner / builder

Despite now making a living from racing, the hillclimb project is still very much a source of entertainment for Valman: 'What has been fun is, at the beginning, I didn't know how to do a lot of things. It's been a process of learning, asking how does this work? How do teams approach things in different series? What is the maths behind everything? Then each topic you just get in deeper and deeper, that's the entertaining bit about it.'

Such is the enjoyment of the process, the actual racing side of the project is something of an afterthought. 'It will go to a team, and they will operate it. I just want to build it!'

The engine Valman has chosen is a Hartley Enterprises H1 V8. The 3.0-litre, turbocharged unit is essentially two Suzuki Hyabusa fours running on a common crank, so is lightweight, high revving and powerful enough for this application



The power unit has been left largely stock, though Valman has made some changes to the valvetrain and designed and fabricated his own breathing and cooling systems, incorporating a pre-heating capability for the engine oil supply

'At the beginning, I didn't know how to do a lot of things. It's been a process of learning, asking how does this work? How do teams approach things in different series? What is the maths behind everything?

Almost every element of the car has been designed and, in most cases, manufactured by Valman, with the exception of parts such as dampers and sensors. The central chassis is constructed from T45 tubing to a design dictated by both FIA regulations and a quest for ultimate torsional stiffness. 'There's a bunch of regs in terms of where bars need to be from the FIA, but they don't specify a huge amount of what forces those bars need to take. They say you need a bar here, here and here, and they need to be of this dimension. I was working within those, but also looking at how stiff I could make it before I may as well have gone to a composite chassis.'

Construction of the main chassis is one element he outsourced, with fabrication taken care of by UK-based JP Cages. '[Josh] primarily makes rollcages, but took this on as I needed someone who knew what they were doing with T45. He thought it was a fun project and was happy to take it on so long as he could talk about it [on social media].'

The chassis build took place relatively early in the car's development. 'Probably too early,' admits Valman. 'There are quite a few areas where I have chopped and cut bars to move and change things.'

The weight of the bare chassis is around 80kg – perfectly acceptable – and, while a move to composite could have potentially saved 30kg, the complication that would have added if any elements need changing ruled it out. 'The main thing I would have got with a composite chassis is not having to fill in all of the holes with panels, which means mounting brackets and other hardware.'

Evolution in design

The suspension is double wishbone front and rear with inboard, longitudinally-mounted coilover dampers (supplied by Öhlins) actuated via rockers. Anti-roll bar duties are handled by torsion bars and there is a front third element, with a rear also planned. 'I just haven't got around to that yet,' says Valman.

The main suspension members are fabricated in-house from steel, while the pushrods are machined from billet. 'I'd like to do them in carbon, but I don't have the confidence yet to make them myself.'

A key tenet of Valman's design philosophy was ensuring the chassis is adaptable

Even the uprights are entirely owner made, produced from 7075 aluminium with S316 inserts, with the axles machined from 300M and featuring an M55 x 3 thread to accept homemade wheel nuts.

A key tenet of Valman's design philosophy was ensuring the chassis is adaptable. 'I did the suspension early on and, from everything I read, the key was don't fix anything.'

With the variety of course types found in UK hillclimbing, adjustability is even more important than with a circuit car. 'Obviously, you need a very tight turning circle for a lot of the European tracks,' he notes, adding, 'but some of them are bumpy, some are smooth, some have lots of tight corners, others far fewer. It's not like you can set a car up for one circuit and probably be within 10 per cent on the next circuit. In hillclimb, you could be 40 per cent out on some of those dimensions, depending on the track.'

Consequently, there are trade-offs. Make everything infinitely adjustable and things get heavy, so Valman has tried to strike a balance between on-car adjustment and having the ability to change whole assemblies quickly: 'Quite a lot of the car is modular. There are hard points in various places and you can drop in new arm and things like that.'

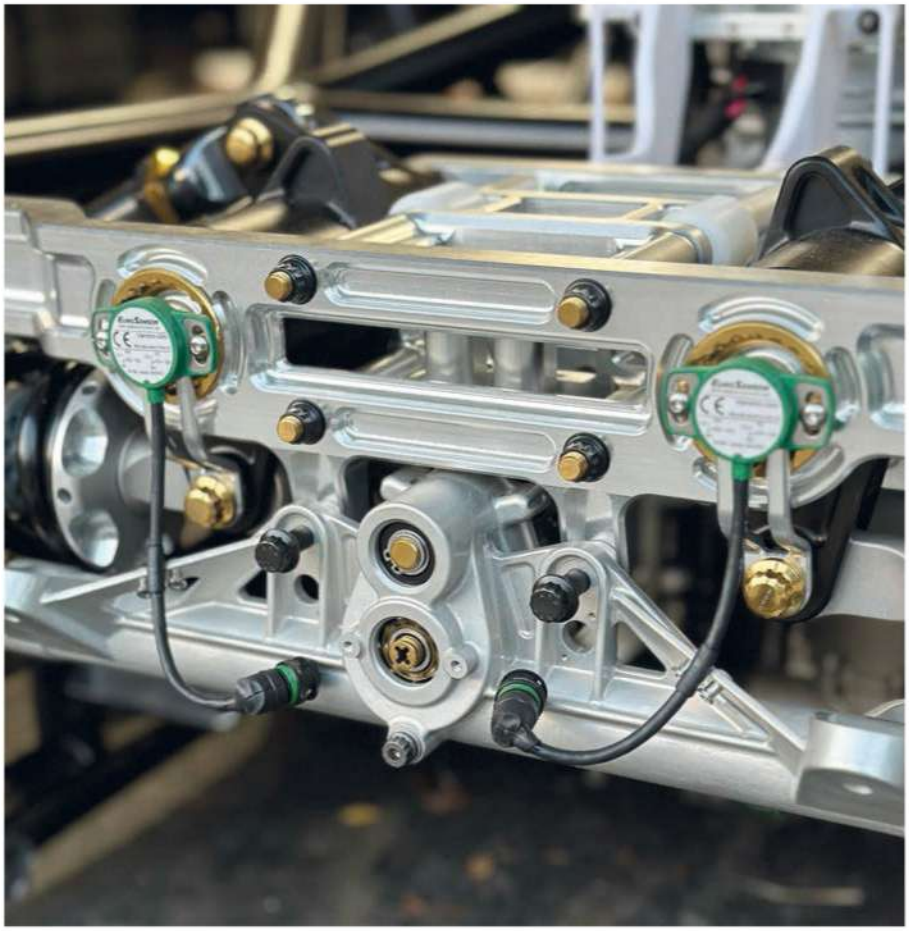
Made to measure

Valman has even manufactured his own steering rack, as he was unhappy with the off-the-shelf solutions available. It is a two-stage design to provide an adjustable ratio and accommodate the extreme lock needed for some courses. Mounting the pinion above the rack allowed him to package it in such a way that it doesn't interfere with a cooling duct located below it. The housing is machined from aluminium billet, while the rack and reduction gear for the electronic power steering are helical ground from hardened 4130.

Looking across the car, it is evident most of the parts are machined, with only limited use of additive manufacturing, or other construction methods. There is good reason for this, says Valman, because it is what he knows best, and can guarantee the quality of: 'There's a little bit of additive stuff, but we didn't have huge capacity for that, and it's expensive to run, whereas running the CNC is a bit cheaper. It's also the world I know.

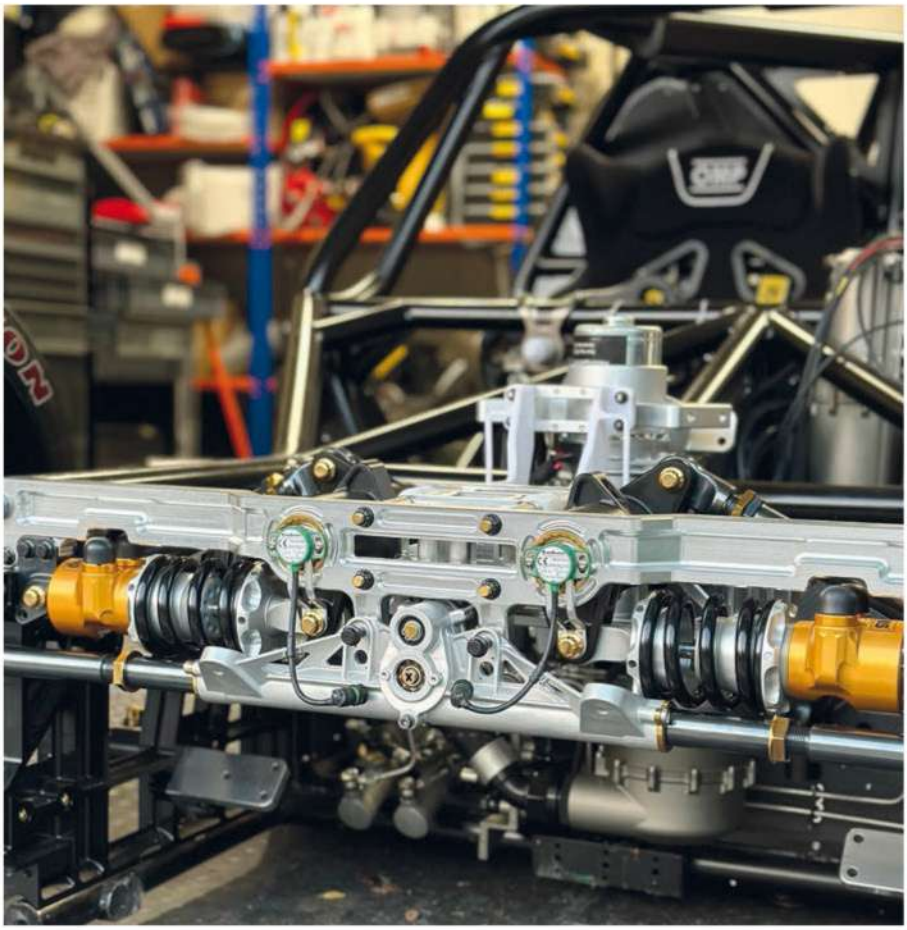
'With a lot of the additive stuff, I just don't have the experience yet to say that looks fine, without scanning it. If I machine from billet,

With 20 years' experience in CAD, the design side of the project was relatively straightforward for Valman, but with his experience being in manufacturing, rather than motorsport, he freely admits he had a great deal to learn



Very few items have been bought in for this project, but the Sadev SL90-20 six-speed transmission is one of them, although Valman has made his own billet end casing that incorporates the rear suspension and wing pick-ups

Cockpit safety structure was made out of house in T45 tube to Valman's design, starting with the basic FIA regulations for a hillclimb car, but then with additional thought given to increasing torsional rigidity to be on par with a carbon tub



Suspension is double wishbone front and rear, with horizontally opposed Öhlins coilover dampers actuated by rockers. Components are a mixture of fabricated steel and machined billet, with possibly some carbon parts to come in the future

I know how it's heat treated and am happy that it is safe. If you're Cosworth, or Pankl, or someone like that, you can print the part, scan it and be sure the material structure is what you want, but I can't do that.'

Composites are a different matter, though, and Valman is busy developing his in-house capabilities in that area, with an oven and equipment for dealing with prepreg materials. Much of the pipe work for the intake and coolant system, for example, is produced from carbon fibre, and he says he'd like to buy an autoclave in the future, though caveats that with, 'the operating cost hurts more than the actual purchase price!'

Driven by detail

Though developing his own engines, Valman opted to use a modified Hartley Enterprises, 3.0-litre, turbocharged H1V8 for this project, which he has left more or less stock. 'I've made some changes to the heads, so I can rev it a bit higher without blowing up but, other than that, most of the changes are to the cooling system and to help packaging,' he explains.

For example, the valve covers have been re-designed to accommodate various mounting brackets and the crankcase vacuum control system. Everywhere you look on the engine (and the whole car) there are meticulously engineered details.

Take the oil tank. The main tank has three compartments; oil is returned (after an air separator) to the top of the tank. The main oil line returns to a central chamber, which rough filters through the air separation central section and into the base. The air / spew return from the air separator is released separately into the outer air chamber, while a small bleed hole from the central section to the air chamber prevents a vacuum. The fill port on top of the tank can be replaced by an external immersion heater. The concept should ensure that only cool, deaerated oil returns to the bottom of the tank. Venting is taken care of via a -4 line running to a baffled, 3.0-litre surge tank.

Oil cooling, meanwhile, is handled by an oil-to-water heat exchanger, again of Valman's own design, which allows for pre-heating the oil system before a run.

'There's a little bit of additive stuff, but we didn't have huge capacity for that, and it's expensive to run, whereas running the CNC is a bit cheaper. It's also the world I know'

'Since I got into engineering as a kid with *Robot Wars*, I have been trying to make things as light and as strong as possible, so this project wasn't too far from the type of work I was doing back then'

Transmitting power from the V8 is a six-speed, Sadev SL90-20 transmission, but you would be foolish to think even this well-engineered part has been left stock. 'It is a transmission designed for short circuits and hillclimbing, but I've made quite a lot of modifications,' notes Valman. This includes producing a new billet end casing that incorporates the suspension and rear wing mountings, with extensive FEA undertaken to ensure it can handle the loads. He also re-designed the oil pump and integrated oil temperature and pressure sensor.

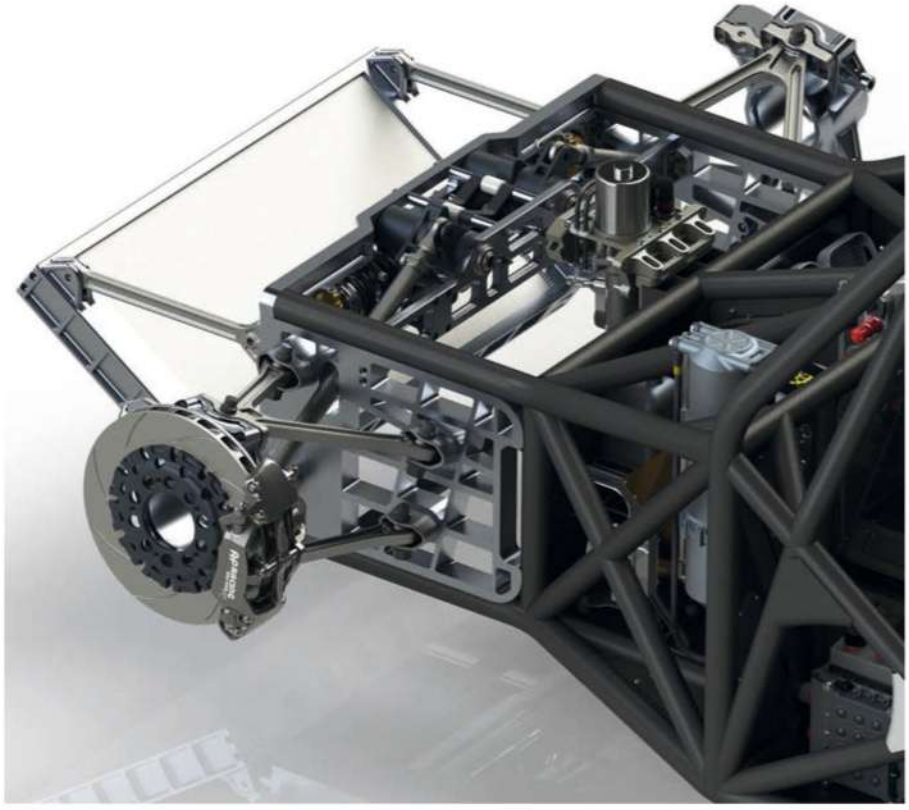
Though not a primary goal, the revisions save around 200g, and that figure could increase as Valman is considering machining an entirely new casing as well.

Sensor and simulation

With his background in manufacturing, Valman is clearly very adept with CAD, but has also been able to expand his knowledge and expertise in simulation. Every element of the car has been analysed in some way: 'I do most of my work in Ansys, so that is the main limitation at the moment for my simulation,' he notes. 'Most of what I am doing is between Excel and Ansys. But since I got into engineering as a kid with *Robot Wars*, I have been trying to make things as light and as strong as possible, so this project wasn't too far from the type of work I was doing back then.'

Of course, any simulation is only worthwhile if you can gather real-world data to validate it, and this is an area where Valman has gone to town; his car is sensored up to the nines. 'Anything that might get hot has a temperature sensor on it. Everything that might move has both a motion sensor and usually a vibration sensor as well,' he says.

Obviously, Valman was not going to settle for a low-grade wiring loom connecting all these sensors, so he taught himself the noble art of motorsport wiring, too. 'There was one Christmas where I had two weeks off and not so much to do, so I sat down to learn how to do proper harnesses, concentric twisting, all of the mucking about with tiny pins. I think there are something like 4000 pins across the car.'



The whole car has been approached in a modular fashion, allowing for ease of adjustability and even complete replacement of whole sections if necessary for the vastly different courses the European hillclimbing championship visits

Valman designed and made the adjustable electronic power steering rack with the ideal ratio and lock for hillclimbing, machining the housing from aluminium billet and the rack and reduction gear from helical ground hardened 4130

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'I'm running all of the machines myself, fitting parts in when we have down time, and materials don't cost all that much. It only starts to cost a lot when you go out of house'

Data logging and engine control are handled by a MoTeC M190 ECU with a PDM 32 to boot, as well as an SVIM (synchronous versatile input module) to handle extra sensors. 'Data is my interest and, to be honest, you don't need that many sensors in a hillclimb car, but I want to keep developing it and get the data off it to understand what can be changed.'

The 'Alfa' is clearly still a work in progress, and its track debut will hinge on Valman finding the time to design and create the bodywork to clothe the exquisite chassis. The final form is still TBC, but he's not too worried about that, for it is the journey that matters most: 'It will probably plod along for another year or two.'

Scope creep

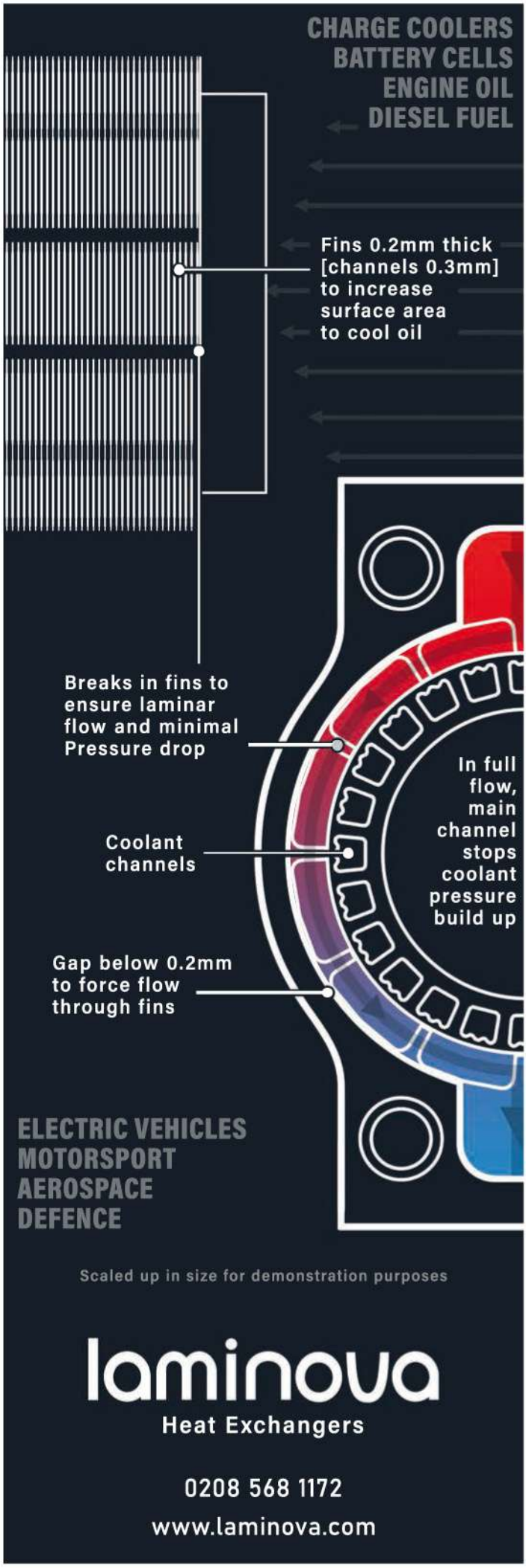
To say the development scope of the car escalated would be an understatement. Valman has become so engrossed in the mechanical design that the bodywork has taken a back seat. 'I know machining, so I know how to design parasolid stuff but, when you get into really detailed surface modelling, I'm still a bit lost, so need to learn how to do that.'

To some, this may seem a frivolous project and, as he has plotted its progress via Instagram (@motorsport_engineering), there have been plenty of comments along the lines of, 'Great, but you're spending x-million quid on this,' or similar. 'I never set out to have people follow it,' says Valman, 'and when people suggest I'm spending lots of money on it, I have to point out it doesn't actually cost that much. I'm running all of the machines myself, fitting parts in when we have downtime, and materials don't cost all that much. It only starts to cost a lot when you go out of house.'

That one person, even one with Valman's years of manufacturing experience, has designed and produced this chassis at home is impressive, to say the least. Look at any aspect of it and the quality of the engineering and manufacturing work is evident, right down to the cable clips that are CNC machined to Valman's own design. When it does finally hit the track, this 'Alfa Romeo' is sure to perform just as impressively.

Just about anything that moves on the chassis has a sensor attached to it, its position and mounting designed in from the start. The idea being that once the car is up and running, data capture will come quickly to help in its development

The quality of engineering and manufacturing is evident wherever you look on this project, from tiny parts like the CNC-machined cable clips to complex parts like the supension rockers. Indulgent? Perhaps. Frivolous? Maybe. Inspiring? Yes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In the beginning…

Sportscar newcomer, Genesis, is aiming to balance pragmatism and ambition with its WEC effort

By DANIEL LLOYD AND ANDREW COTTON

Photos: Genesis

Team principal, Cyril Abiteboul (left), wants Genesis to be competing for wins in 2028, but knows the first season will be a challenge

It has been 10 months since Genesis announced it would be entering the FIA World Endurance Championship (WEC) in 2026. A lot has happened since then, and the Hyundai-owned luxury car brand has taken several steps towards readiness. It has chosen a chassis supplier for its LMDh car, selected and fired up the engine, partnered with an LMP2 team to train its crew and formed a leadership structure with a high level of experience.

By the time you read this, the Genesis GMR-001 might be on the cusp of its first track test, scheduled for early August. The car is due to make its competitive debut at the WEC's season opener in Qatar in late March 2026, just 18 months after the project was revealed to the world.

Of course, some preliminary design work took place before sign-off, but it is still a relatively short gestation period for a Hypercar. By comparison, Ford announced its LMDh effort more than two years before its planned debut, and fellow 2027 arrival, McLaren, went public with its announcement only three months after the Blue Oval. If Genesis hits all its targets, it should have no issues, though there is little room for error.

The tight timeline Genesis set itself required the company's motorsport leadership to carefully map out every element of the GMR-001's development. 'The approach was always going to be a very pragmatic [one], leveraging a combination of proven technology and know how that we have in-house,' says Cyril Abiteboul, team principal at Genesis Magma Racing. 'At the same time, [calling upon] proven skills and experience from established partners.'

The proven technology is the GMR-001's engine, which is derived from that which powers the Hyundai i20N Rally1. But where the rally car uses a 1.6-litre, turbocharged, inline four producing around 400bhp, the LMDh melds a pair of them into a 3.2-litre, twin-turbo V8 with direct injection. This will need to achieve up to 530kW (710bhp) to be competitive, staying as close to the maximum permitted torque curve as possible.

Rally technology

Genesis won't be the first Hypercar brand to use off-road engine technology; Glickenhaus developed a 3.5-litre, twin-turbo V8 out of two rallycross engines from Pipo Moteurs, which, ironically, built WRC units for Hyundai in the past. Although Hyundai has been making its own WRC engines since 2017, the current Rally1 engine is built to the same Global Race Engine blueprint as the one that Pipo used to provide it with. So, the Genesis LMDh and Glickenhaus LMH share common ancestry in the GRE rule set, used by both WRC and WRX, and base engines that can trace their roots to Pipo's design office. The Genesis LMDh unit is built at Hyundai's rally headquarters in Alzenau, Germany.

Genesis won't be the first Hypercar manufacturer to use rally engine technology

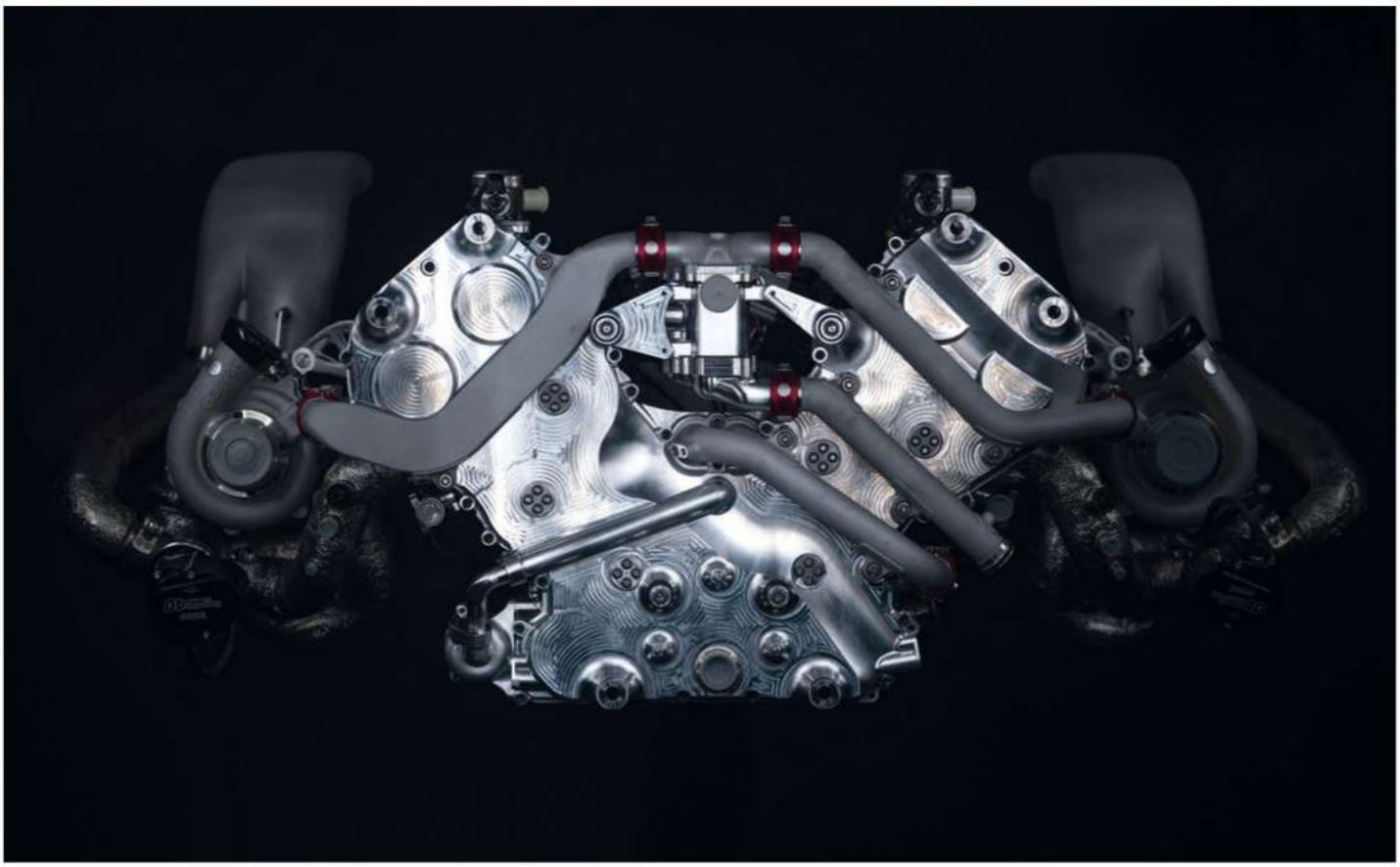
'Conscious of time, we tried to be very conservative and carry over as many parts from our rally engine as possible,' explains François-Xavier Demaison, technical director at Genesis Magma Racing. 'We wanted to keep the unit capacity of 0.4 litres [per cylinder]. As a technical director, I would always go for the smallest engine possible, but we saw that it was maybe a bit too ambitious to go to a 2.4-litre V6.'

The LMDh engine won't rev higher than its WRC counterpart, the valvetrain being designed for a more appropriate range. One challenge has been reducing the engine's weight to ensure the car reaches the 1030kg regulatory minimum. Demaison says the team also has 'ambitious targets' for fuel consumption, but needs time to meet them.

The GMR-001 engine was fired up for the first time on 28 February. It was on time, but it still left only four months to further develop it before installing it for a full car fire up in July.

'Four months, that's insane,' remarks Abiteboul. 'It's never been done. That's why I speak about being pragmatic, working with partners and using existing solutions.'

While Genesis could lean on proven in-house technology for its engine, the tight project timeline forced its hand in other



Design work for the 3.2-litre V8, which is derived from Hyundai's 1.6-litre, four-cylinder Rally1 engine, started in June 2024 and the first fire up occurred on time in February 2025

aspects. Chief among them was the choice to build an LMDh car instead of an LMH. The latter would have required Genesis to develop the entire car in-house, including a hybrid system. Choosing LMDh means the GMR-001 uses a spec hybrid system and gearbox, as well as a base chassis that has already been developed. This is cheaper (though more expensive than Abiteboul expected) and more achievable, timing-wise, than building an LMH from scratch.

Logical choice

Genesis considered going to Dallara for the chassis, but ultimately reached a deal with ORECA. There were multiple reasons for this, not least the logistical consideration of ORECA being based in the same industrial park as IDEC Sport, the LMP2 team with which Genesis is training its mechanics, engineers and potential drivers in the European Le Mans Series.

'Dallara has everything from the wind tunnel to the sim' to the hydrogen facilities,' says Abiteboul. 'I was almost a bit concerned there was too much for us to appreciate what was the number one priority, that there was a risk of us being a bit lost in the world of potential. In ORECA, I don't want to sound negative or derogatory [towards] our partner, but it's [more] basic. We know that the basics will be right, because the LMDh cars are vastly inspired by LMP2 regulations. And if you look at the LMP2 market, it is very clear [ORECA has been successful]. For us, there was absolutely no risk in going for ORECA.'

> **'For us, there was absolutely no risk in going for ORECA [for the chassis]'**
>
> *Cyril Abiteboul, team principal at Genesis Magma Racing*

Partnering with IDEC Sport has enabled Genesis to quickly embed itself into the endurance racing ecosystem. IDEC is an experienced team, now in its 10th season of LMP2; it won the ELMS title in 2019. Its sporting director is Nicolas Minassian, a former Peugeot LMP1 driver who has been recruiting for the Genesis project. To be based at Paul Ricard, Genesis had to register as a new company with the French government. At time of writing, this process was due to be completed by July, after which employment contracts can be created for non-powertrain staff.

Genesis revealed its leadership team at Le Mans in June: touring car legend, Gabriele Tarquini, has become sporting director; Le Mans-winning strategist, Justin Taylor, is chief engineer; while former Kessel Racing programme leader, Anouck Abadie, is team manager. Genesis is building its cars in a converted warehouse at IDEC's headquarters, although the French team won't be running them in the WEC. Its purpose in the project is to give Genesis a leg up, given the limited time and resources available.

Ambitious targets

It would be wrong to mistake Genesis' pragmatism, by seeking external help, for a lack of ambition. Abiteboul has set the goal of contending for podiums in year two of the programme. He then wants the GMR-001 to be vying for victories in 2028.

'That is what I have in mind,' says the former Renault F1 boss. 'Maybe it's a bit arrogant, I don't know. But I think it's the spirit of the regulations to give all teams that have been making the right decisions at the start of the project, the opportunity to stand a chance. I want to believe we are making decisions now that will give us a chance of winning in three years' time.'

Those aims are made increasingly lofty by the fact Genesis is building its own race team from scratch. Magma Racing will be the factory squad, named after the road car special projects division within Genesis. This is what Peugeot did when it arrived on the scene in 2022, but it's unusual. Aside from Toyota Gazoo Racing, which had already been in the game for years, most Hypercar OEMs have partnered with established race teams. These include Ferrari (AF Corse), Cadillac (Jota), BMW (Team WRT) and McLaren (United Autosports). In doing so, they have sought to avoid any chinks in the operational armour,

especially in such a large and competitive field. Abiteboul reckons Genesis' approach, although risky, demonstrates its long-term commitment to sportscars.

'If it had been a programme of a couple of years, maybe there would have been different ways of doing things,' he says. 'Probably, we could have gone into getting a partner team to race the car for us. It's because we see that more as a starting point. We want to build the expertise, understanding, control and authority on circuit programmes.'

Electronics splurge

Software is one of the hidden battlegrounds in the Hypercar category, one of the few areas where open development is allowed, in a class where cars are homologated for five years and can only receive a limited number of performance updates with the organisers' approval. As a relative latecomer, Genesis has much less data to go on than its rivals. So, it has gone to the upper end of the market with its electronic control unit (ECU). The GMR-001 will use the new TAG-700 from McLaren Applied, which Formula 1 will be adopting in 2026.

'I have [had] very good experience with TAG in previous life,' says Demaison, who was technical director of the Williams F1 team in 2022. 'I think when it's a software war, it's important to have the best in the market. The engine is running on the powertrain dyno; it is working. We started work with the TAG-510 version because it was not at the level for a V8 when we started running on the dyno.'

Genesis knows its maiden WEC season will be one of learning. It will also be one of data acquisition, not just for the team but for the FIA and ACO, which set the Balance of Performance

By going with McLaren Applied, Genesis is having to write its own ECU code. This is a mammoth undertaking, for which it has been recruiting staff, although rival manufacturers have already hired good people. Other available systems come with pre-written code that Genesis could have customised at less effort and expense. This has been the favoured approach of multiple manufacturers, a known exception being Acura, which also uses McLaren Applied. How does Genesis' decision to take the more challenging route square with the development time crunch it is facing?

'We went for what we believe is best in class, even if that means more cost, or time, to get it up and running,' explains Abiteboul. 'We are very focused. We already have quite a lot of people working from different places in the world. Everyone is working from their own location, until such time that we have one location where everybody can get together. A lot of them are working remotely from home, a couple in [Alzenau]. The progress we are making on the software side is then being validated on the simulator.'

Genesis recently ordered a new driver-in-the-loop simulator from Dynisma. It has not been installed at Paul Ricard yet so, for the time being, the team has been using a commercially available one at Dynisma's UK base to calibrate its vehicle models.

Heading to track

Virtual testing is one thing, but what the sportscar world really wants to see is the GMR-001 on track. That has been scheduled for early August. Testing will take place solely in Europe until the car's homologation sign-off in December. As much as the team would like to run the car at Sebring, time is not on its side. At least the ORECA chassis, which is also the base for the Acura ARX-06 and the Alpine A424, has been to the bumpy Florida circuit before.

'That is a compromise we had to make in relation to the time,' says Abiteboul. 'We would have loved to have [tested elsewhere], but logistically it was impossible. We will go to different characteristics of track in Europe.'

Genesis knows its maiden WEC season will be one of learning. It will also be one of data acquisition, not just for the team but for the FIA and ACO, which set the Balance of Performance. Genesis is involved in technical working group meetings with the FIA, but is not yet at the table for meetings between the manufacturers where the state of endurance racing is keenly discussed. However, it will enter the lion's den very soon.

Genesis

Genesis is using its LMP2 campaign with IDEC Sport this year as a 'trajectory programme' to operationally prepare for running its own Hypercar team, starting in 2026

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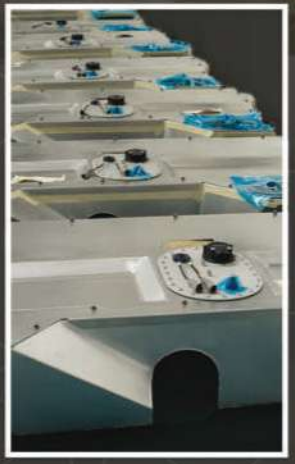

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Taste of the future

Hydrogen cars are scheduled to race at Le Mans, but what will they actually be like? Cranfield University students have given us an indication

By DANIEL LLOYD

Images: Cavendish Motorsport

The Cranfield Group Design Project is an important part of the university's MSc programme, giving students a taste of how to design and present a concept for a complete racecar

The 24 Hours of Le Mans could conceivably see its first hydrogen car on the grid in 2028. Three years out from that date, it is hard to visualise what the highly anticipated cars will be like. Some manufacturers have offered glimpses; Toyota, for example, revealed its liquid hydrogen-fuelled GR LH2 concept car at Le Mans this year. Alpine has built a demonstrator with hydrogen internal combustion engine technology and the ACO-backed Mission H24 initiative is developing a faster, longer-lasting version of its prototype using liquid fuel.

So far, though, all those official projects have only divulged a minimal level of detail. What performance metrics will hydrogen cars deliver? What structures will they incorporate? How will the storage system affect aerodynamics?

Answers to these questions, and more, were recently posited by groups of engineering and mechatronics MSc students at Cranfield University in the UK. Each year, Cranfield sets its cohort a Group Design Project (GDP), which forms a major part of the course, in addition to theoretical research and thesis writing. The 2025 GDP asked students to form teams that would design a hydrogen Hypercar for Le Mans.

Teams had just 11 weeks to formulate their designs. They then presented their work to an audience of industry experts who voted for the most credible engineering solution

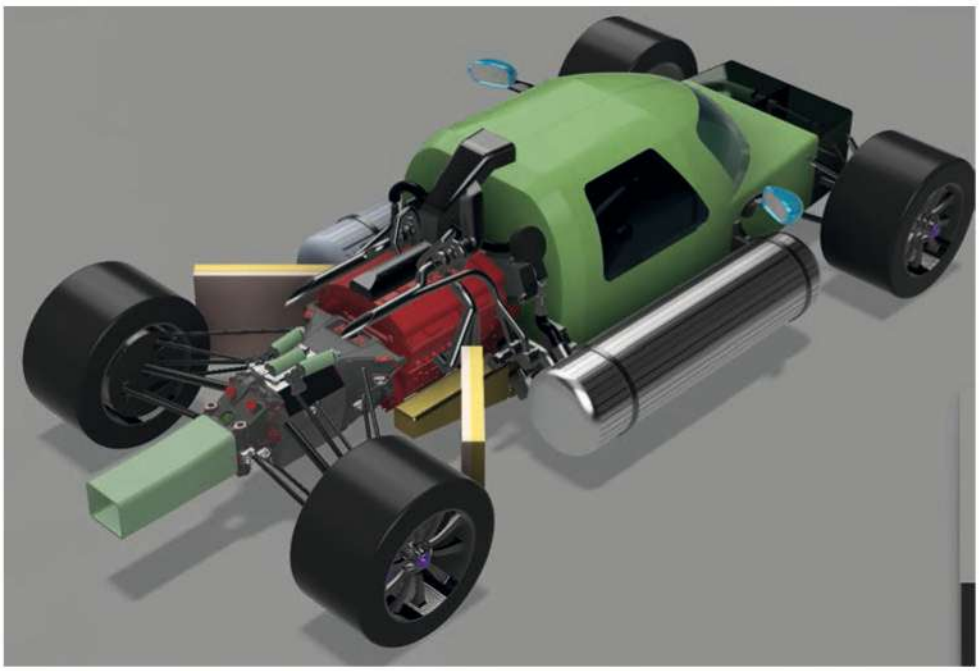
Draft FIA hydrogen regulations were shared with the students to help guide them. However, as they are incomplete, teams also referred to the existing LMH and LMDh regulations to fill in the gaps. For example, hydrogen storage criteria were available, but not stint energy limits.

Teams had just 11 weeks to formulate their designs. They then presented their work to an audience of industry experts who voted for the most credible engineering solution. This year's winning team was Cavendish Motorsport, whose proposal for a hydrogen ICE prototype capable of lapping at 3m27s in qualifying trim is detailed here.

Hydrogen pioneer

The team is named after Henry Cavendish, the British scientist who discovered hydrogen in the 1760s. Apt considering the pioneering work currently taking place in endurance racing. Cavendish's target for its car was to lap the 13.626km Le Mans circuit at 3m36s in race conditions, and 3m26s in qualifying trim. It wanted it to reach a top speed of 347km/h and complete 311 laps in 24 hours.

'For our lap time simulation, we used a custom pre-track bicycle model,' explains Andrew Smith, who opened the Cavendish



Cavendish established a hydrogen fuel fill rate of 5.32MJ/s, based on scaled times from the existing Toyota GR Corolla H2 project

team's presentation. 'This is similar to a quasi-static model, just adding an additional bicycle model to account for differences in front and rear axle sensitivities.'

Running this model enabled Cavendish to define some key parameters for the car, including a frontal pressure balance of 47.5 per cent, a frontal mass balance of 45 per cent and a downforce coefficient of three. Targets influenced by the available rules included wheelbase (3148mm), track width (1990mm) and vehicle weight (1030kg).

The Cavendish car was significantly heavier, at 1300kg, the baggage coming from the twin hydrogen storage tanks and a 'relatively beefy' hybrid system. Each of the tanks weighed 42.5kg when full (32kg dry), excluding auxiliary components such as vents, pumps and valves.

Storage solutions

There are different ways of storing and using hydrogen fuel in a racecar. The FIA's preference is now for liquid storage, although the Cranfield GDP groups explored various other solutions. One team even went for solid-state storage, using 25kg rectangular prism fuel cell blocks that could be slid horizontally out of the car and replaced during pit stops. Cavendish went for the more conventional liquid solution, based on its low volume and low storage pressure of less than 10bar. The team considered making the storage tanks as small as possible to reduce weight and produce quicker lap times that would offset the long refuelling time. However, it quickly realised that the opposite was true; it needed as much fuel on board as possible to achieve the 900MJ energy usage per stint limit of current Hypercars.

'We're operating with cryogenic fluid, so we're going to have some amount of evaporative loss,' notes Smith. 'We found that, over the course of a stint, this loss equates to about two litres, which is a negligible amount. This gave us a 279.8-litre [19.83kg] tank with a 168-second refuel time. In WEC, that's a pretty long time, but about standard for hydrogen. It [gave a stint] length of 12 laps in fuel save mode and 11 laps in full push.'

Look to the stars

All GDP groups had to propose storage tanks in compliance with the TRL5 technology readiness level. Cavendish approached this by looking to the stars: 'We selected a NASA prototype design that they used for the Griffin spacecraft,' says Smith. 'It has an aluminium internal shell that prevents seepage and is wrapped in a carbon fibre wrap that provides structural strength. Outside of that, we have an insulation blanket and an aluminium foil insulator to reduce the heat transfer coefficient and boil-off. Attached to the tank we have a number of FIA-mandated release devices, as well as a blow-off / boil-off valve to account for any over-pressuring.'

The tanks are positioned within the sidepods and the team calculates it would take 2m48s to fill both tanks, corresponding to a 3m28s pit in / out time at Le Mans.

All GDP groups had to propose storage tanks in compliance with the TRL5 technology readiness level

For its combustion engine, Cavendish went for a 3.5-litre, twin-turbo V6 Ford EcoBoost with water injection. The unit produces 481kW (645bhp) at 8000rpm in the Cavendish car. Turbocharging was required because the team found that a normally aspirated engine could not reach the power target of 450kw at λ=1 while facilitating lean hydrogen combustion.

Unlike the baseline engine, the Cavendish ICE has a variable compression ratio and a slightly higher BMEP of 32bar at 5000rpm. A variable compression ratio was adopted because the hydrogen-fuelled engine gives a higher laminar flame speed and a tendency to knock at low load, which requires a lower compression ratio than the baseline. At higher revs, a reduced residence time lessens the risk of engine knock and the compression ratio can be increased to improve combustion characteristics. Cavendish simulated the engine's headline figures using AVL Cruise M software.

Dual motor

Although optional, every GDP group chose to run a hybrid system. Cavendish did so because the recuperation of electrical energy through braking facilitated downsizing of the hydrogen storage system. It also kept the power up when the ICE lost thermal efficiency at higher rpm.

'We have two separate electric motors on the front axle driving the left and the right independently,' says Ben Watt, responsible for the hybrid system at Cavendish Motorsport. 'We had to decide if we wanted to deploy as much electrical power as possible to the front or not.'

The dual MGU arrangement enabled torque vectoring. Cavendish simulated this using a model of Sydney Motorsport Park, focusing on the high-speed turns four and five, which best represented the high-speed corners found at Le Mans.

'Through this, we implemented a simple controller, to see how much we could get through this manoeuvre,' explains Watt. 'We managed to gain 0.152 seconds through those two turns with higher apex speeds, and only 391Nm difference in torque. In an endurance race, this benefit would be compounded and [result in] massive gains from this technology.'

The braking system combines the hydraulic efforts of the calipers with regenerative braking from the MGU-K, which must be managed by a brake-by-wire system.

Cavendish was keen to validate its sample data for the brake-by-wire using a hardware-in-the-loop (HiL) rig. That mainly tested the solenoid valves and the valve rod mechanism as that was the hardware the team had available. It tested two braking events in HiL, including an MGU-K failure.

In the standard braking event, there was an undershoot from the HiL system compared to the maximum allowed torque curve. In the failure case, the hydraulic system recovered quickly in simulation, but struggled in the HiL, likely due to its physical limitations.

Green structure

Cavendish designed its front impact structure (FIAS) from bio-composite materials. It assessed different options such as carbon bio-epoxy, carbon polylactic acid (PLA) and flax fibre. Considerations included how much mass would be required to absorb 130kJ (a figure extracted from the F1 FIAS test) and how much embodied energy it carried. This is the amount of energy required to create such composites.

'The total embodied energy of flax fibres was the lowest out of the different types we assessed,' says Emma Cheetham, responsible for structures at Cavendish. 'However, it would have added 3kg and 0.14 seconds to our lap time. For a component that adds no performance, as a group we deemed this unacceptable. So we went for a hybrid.'

That hybrid composite with a PLA matrix produced 72.83MJ less embodied energy than carbon fibre with a PLA matrix. It was also the lightest option. Cavendish modelled different geometries for the FIAS, settling on 16 plies with three spars, which returned a peak deceleration of 29*g* at a cost of 9.86kg in mass. All energy was absorbed within 557mm of the FIAS's 650mm length.

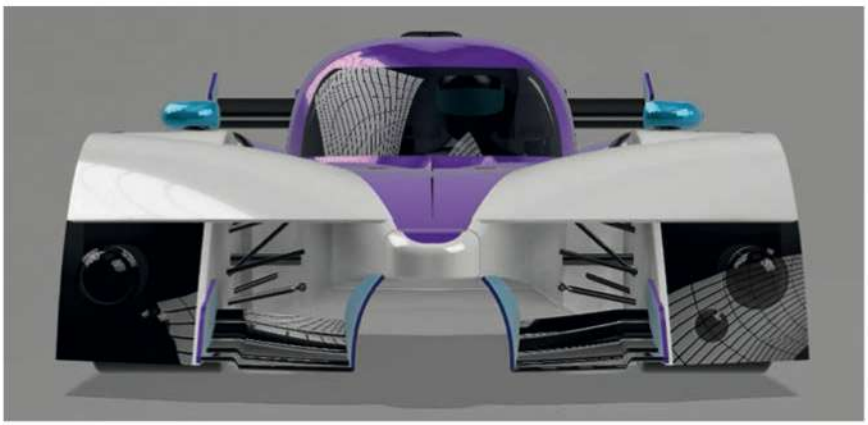
'The benefit of the spars in the middle is that it helps to prevent collapse of the structure inwards as the crashing progresses,' reveals Cheetham. 'Our final deceleration vs displacement is well below the 40*g* limit the FIA has deemed acceptable for F1.'

Aerodynamics

Mounting the hydrogen storage tanks low on the side of the car enabled the Cavendish aerodynamicists to design the diffuser with a later kick bite. This, in turn, influenced the floor's design. A lot of work was also done at the front of the car.

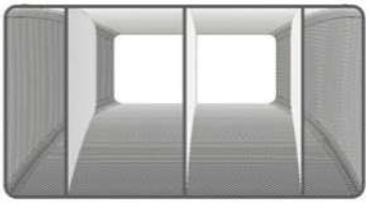
'One of the key features that sets us apart from other Hypercars, and I think is going to produce a lot of downforce, is how we integrated our front wing with the rest of the floor,' says Pranshu Vyas, who worked on the aero. 'Our design has the front wing in a straight configuration around the nose. The floor is placed centrally. That allows for a lot of undisturbed airflow to go through the central intake of the tunnel, at a much better angle of attack as it is not disturbed by the outwash of the wing.'

Cavendish tried to focus most of the low-pressure region on the car's centre to aid its aero balance. A curved diffuser increased the amount of air being drawn, but also created stronger vortices, which was further promoted by strakes. The team went for a single-element rear wing based on the MSHD aerofoil profile.



Images: Cavendish Motorsport

A front wing either side of the nose influences airflow to the floor, which generates 65 per cent of the car's downforce



This is Cranfield's front impact structure, made of a hybrid bio-composite with a PLA matrix. Its chassis is built from recycled carbon fibre and weighs 120kg

'It is heavily cambered,' says Vyas, 'and allows us to keep a lot of uniform suction along the wing, maintaining lots of low-pressure regions in the aft section, which promotes flow extraction from the diffuser and helps with maintaining downforce and diffuser efficiency.'

Aero validations were conducted in CFD, using three grades of mesh. Wind tunnel testing was not possible in the 11 week timeframe of the project. The results illustrated a 40 per cent frontal balance, 142kg drag force at 50m/s and 720kg downforce at 50m/s (2.61 C_L and 4.49 C_{La}). The floor (including upper body) produced 65.8 per cent of the car's total downforce, the rear wing 20.1 per cent and the front wing 13.05 per cent.

Cavendish simulated that its hydrogen Hypercar could lap Le Mans in 3m27.07s… and, when saving fuel, the car could run 12-lap stints. At that pace, it could theoretically manage 313.2 laps

The suspension is double wishbone front and rear. There is a decoupled heave and roll arrangement at the front, consisting of a heave damper, Watt's link primary rocker and a roll damper. A three-spring damper sits at the rear, mounted to the modelled Xtrac P1359 gearbox.

The front suspension prioritised high-speed stability and control, with low camber change, a negative scrub radius of -25.77mm and zero bump steer, as well as 40 per cent anti-dive. At the rear, Cavendish focused on packaging and traction. The system is built with 53.6 per cent anti-squat and an increased roll centre height due to mass being biased towards the rear.

Projected pace

Cavendish simulated that its hydrogen Hypercar could lap Le Mans in 3m27.07s. This would have put it 1.82 seconds off the pace of the slowest qualifying Hypercar this year. However, it would likely be a strong starting point for a hydrogen car in 2028. The average race lap time was simulated at 3m30.10s and, when saving fuel, the car could run 12-lap stints. At that pace, it could theoretically manage 313.2 laps (equating to 4264km), factoring in safety car periods and time spent in the pits, beating its 311-lap target. For context, this year's winning Ferrari 499P completed 387 laps and saved over 40 minutes in the pits against the Cavendish car, assuming the latter did 26 12-lap stints.

The Cavendish group project gave an insightful look at how a hydrogen Hypercar might come together, and how it could potentially perform. Equally interesting presentations from GS Racing, Marlin Motorsport and Tritium suggested that the future of sportscar engineering is bright, and that the category will be in safe hands as it heads into its hydrogen era.

Cavendish Motorsport is Edurne Berlanga, Emma Cheetham, Robert Courtney, Steve Imboden, Blake Kuhlmann, Arnav Singh, Will Schoeman, Shwetaank Modi, Andrew Smith, Pranshu Vyas and Ben Watt.

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Formula for success

A plan for revitalising the career path in single-seater racing. Part 1 – Formula Ford

By DANNY NOWLAN

Unless you have been living under a rock for the last 20 years or so, you'll be aware that spec racing, or at least ever-increasing technical restrictions, has become commonplace in single-seat, open-wheel formulae. As someone who learnt their trade when regulations were open, I have been watching this situation not just with regret, but increasing alarm.

The reason being that open-wheel single seaters are critical for learning the trade, whether that be as a driver or an engineer. The late author, Carroll Smith, explained it well by saying if you learn how to fly an F-16 fighter jet, going to a Cessna is easy. But if all you know is a Cessna, there is no way you can fly an F-16.

That may not be entirely accurate from an aviation perspective, but the meaning is clear: if you learn how to fly high performance and high precision, going backwards is easy. Motorsport is the same way. Open-wheel single seaters require you, from both a driver and from an engineering perspective, to be precise. Master this and the likes of touring cars and sportscars are more straightforward. It's a lot harder to go the other way, which is why dumbing down single-seat formulae is so dangerous.

Building block

For me, the most important building block of all is Formula Ford (FF). For those of you unfamiliar with the category, it's a single seater with no wings, tube frame chassis, semi-slick tyres and a 1.6-litre Ford Kent engine (later a Ford Duratec). On the old Kent engine, power output was 100bhp, while the Duratec bumped that to around 130bhp. This was the formula drivers used to jump to straight after karts. Ayrton Senna, Nigel Mansell and Mark Webber were all graduates of this system, along with many others.

Formula Ford still exists today, but its spot on the Formula 1 ladder has been replaced by FIA Formula 4, which is now the first port of call for karting graduates.

In terms of regulations, Formula Ford is a very interesting formula and it's where I cut my teeth in racecar engineering. Wings and the use of wind tunnels were banned, engines and tyres were spec, cars ran with

The Formula Ford Festival was a prestigious event in the world of motorsport and an excellent training ground for both engineers and drivers. What is needed now is a similar, back-to-basics series for young engineers to learn their trade

open diffs, third springs were not allowed (although you could play with monoshocks, and it offered me my first exposure to them) and there were limits on both wheelbase and track. Oh, and no carbon fibre!

Apart from all that, it was a case of knock yourself out. Dampers, springs and anti-roll bars were all free, as was data acquisition. That latter part was an absolute godsend as I was learning my trade.

Lessons learnt

The first thing that made Formula Ford so critical as a learning tool for me was the tube frame chassis. Let me explain why. Right up until the early 2000s, Formula Ford was a critical rite of passage for any emerging driver. Consequently, the racing was rough and tough and there were regular collisions. The long-standing joke when the Australian Grand Prix first moved to Melbourne was that you knew when the Formula Fords were on track because you could hear the cars crashing.

Open-wheel single seaters require you, from both a driver and from an engineering perspective, to be precise

In that environment, tube frame chassis are your best friend because they are cheap to build and so readily repairable. When you have chassis damage on a carbon tub, you are done for the weekend. And so is your bank balance. As a case in point, when I was working in Formula 3000 in 1999, at Monaco my driver binned the chassis because he forgot to brake. The repair bill was £30,000 (approx. $40,700), and that was 1999 money!

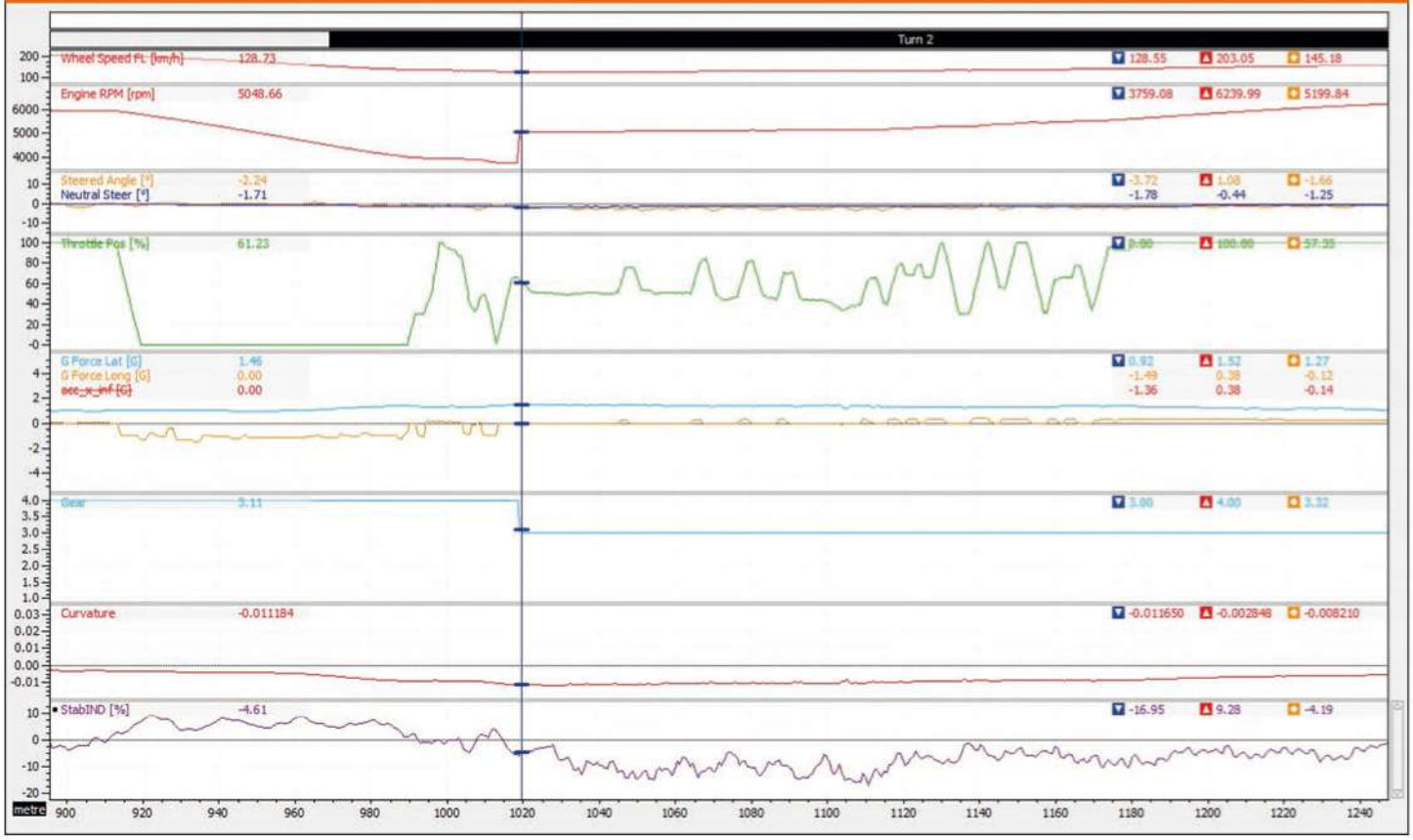
In contrast, even if you have a big hit on a tube frame car, provided you have access to a welder and a jig, you may be done for the day, but you'll have the car back out again the following day. Sure, the driver will – quite rightly – get a bollocking for it, but you get to fight another day, and you don't break the bank. That's such a key lesson that has been lost in this sport in recent times.

The other thing Formula Ford teaches you is how to rotate a car on turn-in. The data trace in **figure 1** of a Formula Ford car simulated on ChassisSim speaks volumes. Pay particular attention to the last trace, which is stability index. Note how high it is at the start on turn-in; at some points, up to seven per cent.

Attitude in action

I have deliberately shown a non-tuned model here because it illustrates the way you drive a Formula Ford. You get the car's attitude into the corner sorted on turn-in.

Fig 1: Turn-in plot for driver parameters on a Formula Ford



Formula Ford teaches drivers and engineers how to interact with each other. As an engineer makes a change that works, the driver can register it and understand what it's supposed to do

To do this, a driver has to develop a sixth sense of what the contact patch is doing, particularly at the rear – something every racecar driver worth their salt needs to learn. If a driver doesn't learn this basic lesson early on, they'll have to master it in higher-spec formulae where car running time is a lot more expensive. Not to mention the inevitable repair bills that will come in the process.

Another key lesson Formula Ford teaches is mechanical grip. The spring rate is in the order of 14-20N/mm at the front (wheel rate) and about 40N/mm at the rear. Those are virtually road car numbers, but combine them with a car that is 'pointy' and it teaches a driver coming straight out of karts how a car really works. Another critical learning experience as they rise up through the ranks. Should they then go into touring cars or sportscars, it also gives them an invaluable frame of reference.

To the lessons Formula Ford offers, you can also add tyre management basics. Let me illustrate this with a story. Because all cars were running on semi-slicks, there was no need for wets. I recall a cold weekend at Sandown, in the outskirts of Melbourne, Australia in 1997. It had been a dry weekend but then, out of the blue on the Sunday, the heavens opened. One of the front runners, who had been doing well all weekend, decided to run fresh rubber in the suddenly wet conditions. Tyre management fail 101. Unsurprisingly, said driver went immediately backwards.

Yes, it sucked for the driver at the time, but how much better to learn that basic lesson at a junior level, as opposed to on the big roulette wheel of F1, or at Le Mans.

Solid foundation

The most important thing Formula Ford taught both drivers and engineers is what can work and what won't work on a racecar. My first exposure to proper data acquisition was in Formula Ford. Likewise, my first real exposure to three and four-way adjustable dampers. I'll happily admit I didn't have a clue what I was doing back then but, without that experience, I wouldn't have the solid foundations on which I built my career. And make no mistake, you need a proper racing environment to learn those crucial lessons, not just a computer with a simulation program.

A follow on from this is that Formula Ford teaches drivers and engineers how to interact with each other. As an engineer makes a change that works, the driver can register it and understand what it's supposed to do. In complete contrast, when the avenues of change are restricted to a very narrow window, you can quickly end up with the blind leading the blind. Again, it's much better for both parties to learn these lessons in the low-pressure environment of a junior formula rather than be thrown in at the deep end higher up the ladder.

F4 has replaced the role that Formula Ford once had. I think that is a mistake. The reason being F4 has wings and a carbon tub, so the stakes are immediately a lot higher if you make an error. It removes the safety buffer that Formula Ford offered, and not just from a cost perspective, but for all the other reasons we have discussed.

So, how do we solve the problem? A starting point would be to re-name the category to something like Formula 5, allowing it to slot neatly back onto the F1 ladder, and base the regulations on what has served Formula Ford well over the years. To save costs, you could allow older chassis to compete. However, it's the technical freedoms inherent in Formula Ford that we really need to apply and champion if we are to avoid a situation where drivers and engineers find themselves out of their depth before their careers have even taken off.

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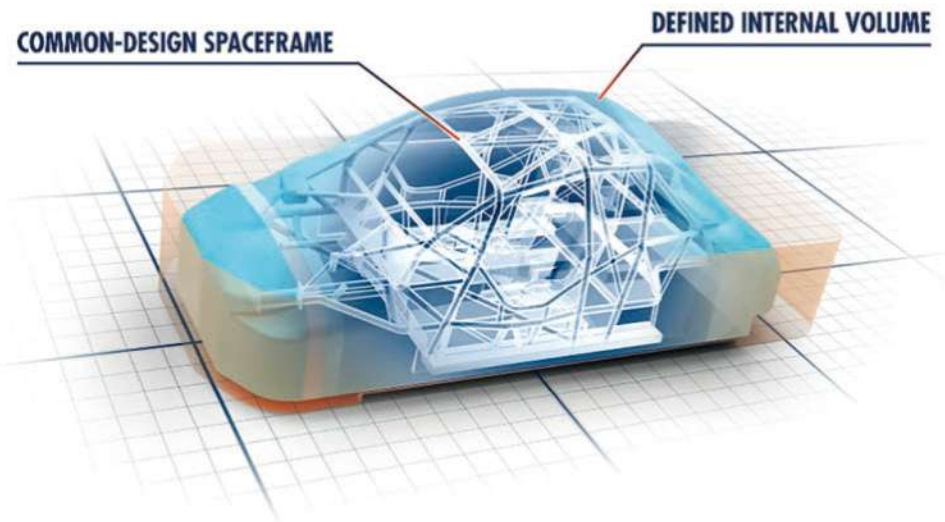
FIA opens door with 2027 WRC regs, but who will join the series?

The FIA World Motor Sport Council has finalised the outline of the WRC27 regulations that will be rolled out in the FIA World Rally Championship. The future top-level cars will feature a common design spaceframe and defined internal volume. All parts of the car must fit within this space, although body design around it is free.

That core tenet of the regulations is to open the door to OEMs that produce different types of car, from saloons to hatchbacks and crossover designs, without affecting performance. The rules are due to remain in place for 10 years, but manufacturers have questioned the lack of a hybrid system in the car in the first iteration of the rules.

It is known that Hyundai will reconsider its position in the championship if there is no electrification option, although the FIA has left the door open for a variety of powertrains, including hybrid, hydrogen and full EV in the future. However, the initial rule set only caters for full ICE cars, and the engine must be to Rally2 specification. Toyota and Ford are likely to stay in the WRC.



FIA

WRC27 was first given the green light by the FIA in December 2024. The Federation has now approved refinements to the reference volumes

Hydrogen steps up with tech regs

The first technical regulations for hydrogen-powered cars have been approved and are set to be integrated into Appendix J of the FIA's International Sporting Code.

The rules have been developed with input from industry experts in aerospace, energy, infrastructure, automotive hydrogen storage, refuelling technologies, system integration, risk assessment and safety engineering, as well as automotive manufacturers and the ACO, which remains intent on introducing hydrogen prototypes into endurance racing before the turn of the decade.

Key safety measures include pressure-testing compartments, multi-alert hydrogen leak detection and boil-off limits. The new regulations only cater to liquid-stored hydrogen, the FIA having turned its back on a gas storage solution as liquid has lower volume and weight compared to the gas tanks that would be required.

All change for Formula Regional rubber

A spec tyre will be introduced to Formula Regional series when they adopt the second generation cars, which are set to debut in 2026.

The FIA has chosen Pirelli as official supplier. The Italian company, which also holds sway in Formulas 1, 2 and 3, will develop new 15in tyres.

In the first generation of Formula Regional, series have been able to choose their own supplier, and four different tyre companies are currently active across five FIA-approved championships. Hankook is used in North America; cars in Japan and the Middle East run on Dunlops and Gitis respectively, while Pirelli supplies the grids in Europe and New Zealand.

Pirelli will also provide tyres to the Formula Regional and Formula 4 races at the Macau Grand Prix.

'This next phase for Formula Regional reflects our ambition to create a truly modern, competitive and accessible platform for developing drivers,' said FIA president, Mohammed Ben Sulayem. 'With technical innovation at its core, controlled costs, and a clear pathway from regional series to the top tiers of the sport, we are investing in the future of global motorsport.'

Pirelli

Current FR cars will be gradually replaced, starting with the 2026 Middle East Championship

HWA special to enter Nürburgring 24 Hours

German engineering firm, HWA, has announced plans to enter the 2026 Nürburgring 24 Hours with a racing version of its own road-legal special.

The HWA EVO is styled on the Mercedes-Benz 190E 2.5-16 Evo II, a successful touring car of the early 1990s. To help showcase the road-legal model, which is limited to 100 units, HWA will develop and run two modified racing versions in the SP-X class for non-homologated vehicles. Full technical spec have yet to be revealed, though *Racecar* understands development will begin shortly. Veteran drivers Roland Asch and Klaus Ludwig, a three-time 24 Hours of Le Mans winner, will be involved in testing.

'During our preliminary testing of the prototype road cars, it was instantly apparent that the HWA EVO is everything we built it to be,' said Gordian von Schöning, chief technology officer at HWA. 'Imbued with both the legacy of the iconic 190E Evo II that inspired it, and the storied success of HWA as a motorsport manufacturer, we are incredibly excited to bring the car to the Nürburgring to demonstrate its full capabilities.'

HWA

The road-legal HWA EVO is powered by a 3.0-litre, twin-turbo V6 producing 445bhp

Ligier launches limited edition track day car

Ligier has launched a non-homologated, track day version of its second generation LMP3 car

The Ligier JS P3X is powered by a 6.2-litre GM LT1 V8 engine from Katech that produces 625bhp, around 155bhp more than today's LMP3s. It has also been given a refined aerodynamics package featuring a new splitter, updated wheelarches and an LMP2-inspired nose that takes in additional air to cool the more powerful engine. A new engine cover, including a dorsal fin evocative of current Hypercars, maintains the aero balance.

The car retains the six-speed, sequential Xtrac 1152 gearbox and semi-automatic pneumatic paddle shift from Ligier's homologated LMP3 model. The double wishbone suspension layout with four-way Öhlins TTX40 dampers is also carried over. Sales are limited to 10 units.

Ligier Automotive

The second generation Ligier JS P320 has been updated with new safety and aero features, as well as a more powerful V8, for this collector's item

IN BRIEF

Reliability issues have caused problems in the new SUV era of the Brazilian Stock Car Pro Series. The fourth round at Autódromo Velocitta in late June has been postponed to September as the series works on modifications to the spec Audace SNG01 platform.

The TCR Australia season has been reduced to just two rounds amid struggling entry numbers this year. The curtain raiser is now set to be held during the FIA TCR World Tour's stop at The Bend in September. A race in Macau is also planned.

Porsche turned heads at the 24 Hours of Le Mans by presenting a one-off, roadgoing version of its LMDh car. The Porsche 963 RSP featured a raised ride height, softened dampers, covered wheelarches and a re-programmed control unit for the lights. It was commissioned for Roger Penske and evokes the Porsche 917 from the 1970s that was re-purposed for road use.

Williams has renewed the contract of its Formula 1 team principal, James Vowles, on a multi-year deal. The former motorsport strategy director at Mercedes joined the Grove team in 2023.

The Racing Bulls F1 team has started using Neural Concept, an artificial intelligence platform that conducts high-speed simulations of CFD designs. Digital twin models create thousands of design iterations and projects how they might work in different environments.

Ram is returning to the NASCAR Truck Series after a 13-year hiatus. The Dodge brand unveiled the Ram 1500 concept vehicle to preview its 2026 challenger. It incorporates elements of the company's Sport Truck range, including Warlock, Rebel and RHO.

Swiss company, Bcomp, has partnered with BMW to produce sustainable bodywork components to the automotive sector for the first time. The company's natural carbon fibre composites will be used in the roof of the new BMW M3.

IN BRIEF

The FIA single seater committee has proposed a Regional Trophy concept for **Formula Regional** and **Formula 4**. These formats will be presented to championship organisers and promoters, giving them the flexibility to choose between a traditional championship format lasting over a longer period, or concentrating the competition into a shorter timeframe.

Driver categorisation is now to be decided by a drivers' committee, with an updated structure. The FIA will preside over the decisions, which will be debated by representatives of the ACO, SRO, IMSA, the FIA Drivers' Committee, regional specialists and two administrative staff from the FIA who will not have voting rights.

Poor weather resulted in the **Pikes Peak International Hill Climb** course being truncated to just under half distance for the 103rd edition. Overall winner was a Nova Proto NP01 driven by 11-time FIA European Hill Climb champion, Simone Faggioli, who completed the climb to Glen Cove in 3m37.196s, beating the Ford Super Mustang Mach-E of Romain Dumas by 15 seconds. A production Honda CR-V e:FCEV became the first hydrogen-fuelled car to contest Pikes Peak.

IndyCar delays to 2028

IndyCar has pushed back the introduction of its new chassis to 2028, due to a delay in finalising the new engine regulations.

Working in tandem with the series' long-term chassis supplier, Dallara, the new car is set to be 38-45kg (85-100lb) lighter and better suited to racing on all of the track types IndyCar visits, with the aim of enhancing overall raceability. Improved safety, a more ergonomic cockpit with improved driver position and an integrated Aeroscreen and roll hoop are key parts of the design.

The development of the new engine, however, is proving to be more challenging. Chevrolet and Honda currently supply the grid and, while the former is set to continue, Honda has yet to commit. IndyCar, meanwhile, has stated the new power unit will be a more powerful, 2.4-litre, twin-turbocharged, V6 ICE that will have an increased reliance on a low-voltage hybrid system that features longer deployment, more horspower gain and overall improved performance.

Xtrac will continue to provide transmissions to the series. The new unit will be 11.3kg (25lb) lighter than it is today and will share parts with the Indy NXT series to reduce costs. Performance Friction Corporation will continue as sole brake supplier.

IndyCar had originally planned to present its new car in May, around the time of this year's Indy 500.

Karl Zemlin

IndyCar will continue to use the venerable Dallara DW12 chassis for another season, with a completely new car now due to arrive in 2028

SEEN: ASTON MARTIN VALKYRIE LM

Aston Martin will produce just 10 units of its new track day car, which is based on the company's existing LMH racer. The British manufacturer says its Aston Martin Valkyrie LM is 'near identical' to the race version, including a matching 697bhp output from its 6.5-litre Cosworth V12. The LMH Valkyrie was itself developed out of a track day car, the Valkyrie AMR-Pro.

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How composites are powering the UK's EV revolution

Lightweighting, innovation and the road to 2030

The UK government's plans to phase out the sale of new petrol and diesel cars by 2030 means we're seeing a huge shift towards the electrification of vehicles. Key to this transition is the adoption of composite materials in the design and manufacturing process, which help produce lighter vehicles, thereby improving their efficiency and range. Here, Simon Farnfield, event director at leading engineering and manufacturing exhibition, Advanced Engineering UK, which returns to the NEC, Birmingham, on 29-30 October, explores the role of composites in lightweighting.

See the latest advances in composite technology and their applications in the automotive sector at Advanced Engineering UK, held at the NEC, Birmingham on 29-30 October 2025

Studies have shown that a 10 per cent reduction in vehicle weight can lead to a six to eight per cent improvement in energy consumption. Composite materials, particularly fibre-reinforced polymers (FRPs) such as carbon fibre and glass fibre, offer a great strength-to-weight ratio. The versatility of composites also means they can be used in various aspects of EV construction, helping to address weight, safety and efficiency challenges, in turn making lighter, stronger and more sustainable vehicles.

Structural components

Composites are increasingly being used in the chassis, body panels and crash structures of EVs. Traditional automotive construction methods rely heavily on steel and aluminium, but advanced, fibre-reinforced composites, such as carbon fibre-reinforced polymer (CFRP) and glass fibre-reinforced polymer (GFRP) offer a superior strength-to-weight ratio. Consequently, a composite chassis can weigh up to 50 per cent less than a conventional steel chassis, improving vehicle efficiency and extending battery range.

Composites also absorb energy more efficiently in a crash, offering better protection for passengers. Furthermore, composites can be moulded into complex shapes, which allows for optimised aerodynamics and reduced drag, improving energy efficiency further still.

Several high-performance EV manufacturers, including the UK's Lotus Cars, are leading the way in composite chassis development, showing how lightweight structures can improve vehicle dynamics without sacrificing strength or safety.

'I come to Advanced Engineering to see what is out there,' said Kyle Richardson, an industrial and manufacturing engineer at Lotus Cars, at last year's show. 'Lotus is on a tech journey right now, so we came to the show to explore new tech solutions. This is my second time attending, and I've learnt a lot. It's mesmerising to see what the industry can now offer.'

Battery enclosures

As the heaviest component in an EV, the battery pack requires a durable yet lightweight enclosure that can provide structural integrity, fire resistance and thermal management. Traditional metal enclosures, often made from aluminium, add significant weight to the vehicle, but composite materials can improve battery enclosure design in many ways.

Composite battery casings can be 40 per cent lighter than aluminium ones, helping counterbalance the mass of EV batteries. They also naturally have lower thermal conductivity, reducing the risk of thermal runaway by preventing excessive heat transfer between cells. Finally, advanced composites can be engineered to provide high impact resistance and fire retardancy, improving the overall safety of battery enclosures.

The UK's National Composites Centre (NCC) is at the forefront of developing these next-generation composite battery casings. As an exhibitor at Advanced Engineering UK, the NCC will be showcasing its latest research into multi-material hybrid structures, which aim to enhance durability and reduce costs for mass-market electric vehicles.

The UK government's plan to ban the sale of new petrol and diesel cars by 2030 is an important milestone on its road to achieving net zero emissions. The shift towards lightweight composite materials in vehicle production will require skilled workers in composite fabrication, automated manufacturing and robotics integration, driving demand for expertise in carbon fibre production and high-rate composite processing.

Thankfully, shows like Advanced Engineering UK help connect manufacturers, engineers and policy makers with cutting edge composite suppliers, technology developers and research institutions to drive such innovation.

Pivotal initiatives

Initiatives like the High-Rate Composites for Electric Vehicles (HRCEV) project are pivotal in developing technologies that facilitate the widespread adoption of composites in the automotive sector. To learn about initiatives like this and more, the Composites Engineering Forum at Advanced Engineering UK will feature presentations from leading OEMs, Tier 1 suppliers and manufacturers on the latest developments in composite materials and processes.

What's more, a newly formed collaboration at the show is helping to push the composites sector forward. Here, PRF Composite Materials is transforming the networking area into a live demo space, where attendees can see composites manufacturing in action and take home a finished part. Meanwhile, the global manufacturer of adhesives, composites and functional polymers, Scott Bader, is leading the newly re-branded Co-Additive Manufacturing Forum, and Composites UK has become the show's exclusive composite partner.

To witness the latest advancements in composites and their applications in the automotive industry and more, attend Advanced Engineering UK on 29-30 October 2025. This exhibition offers a platform to explore cutting-edge innovations, network with industry leaders and gain insights into the future of engineering and manufacturing. Join us at the NEC, Birmingham, to be part of the movement towards a more efficient and sustainable future.

Racecar engineering
Inside the world of modern motorsport technology

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Like-minded people

A new motorsport cluster is emerging, on the side of a French mountain

Circuit Paul Ricard is an extraordinary place. Perched on the side of a mountain at just over 400m elevation, with little else around other than a few quiet villages and rocky outcrops. The location is perfect for a test track, offering privacy and all the facilities you could want to develop a racecar. It even has a private airport next door, and a five-star hotel. Yet the remoteness is changing rapidly and, within the next few years, the area around Paul Ricard will be unrecognisable.

Thankfully, very little is changing at the track itself. Paul Ricard hosted the French Grand Prix on and off between 1971 and 1990. It returned to Ricard in 2018, but has not been held since 2022. The circuit is still used by many other series but is best known for being a test facility.

Ricard was the first to introduce different surfaces, and stripy, high-degradation tarmac in place of gravel traps, which make it quite hard to hit the distant barriers in the event of a spin. However, that's not to say it's impossible to damage your car there. Mirko Bortolotti wrote off a prototype Lamborghini SC63 in 2023 when he crashed at the high-speed Signes corner.

However, behind the circuit is where the revolution is occurring. It is widely known by photographers that certain trees can be climbed to take photos of experimental, or pre-release, cars lapping the track during private tests, but teams are wise to this phenomenon now. Beyond those trees, an entire racing community is developing that looks set to rival the UK's corridor of race teams and services dubbed Motorsport Valley by the Motorsport Industry Association.

A racing community is developing that looks set to rival Motorsport Valley

Motorsport mountain

It has often baffled me why a company the size of ORECA, which is at the heart of this industrial complex, known officially as the Parc d'Activités du Plateau de Signes (PAPS), should choose this part of the world to set up its incredible race shop. You have to climb the mountain to get there, although racing folk know the road well. We know the corners, where the speed camera is, and the jeopardy of visiting on a weekend, when cyclists descend the mountain *en masse*. We also know the frustration of having a good drive spoiled by a truck, which you cannot pass for the duration. At least Motorsport Valley is mostly flat.

Yet, this is where the ORECA race and service trucks are based. They go up and down the hill, one side heading to Marseilles, the other towards Nice. At the top, the company builds its LMP2 cars in vast numbers, alongside the Ferrari 296 GT3 and the LMDh chassis for Acura and Alpine.

ORECA moved to Signes in 1987, and last year opened a new factory at the site. It looks very similar to that of the Aston Martin F1 team, featuring a central aisle, off which lie sub-assembly shops, metrology and carbon fitment.

This shop will produce the LMDh chassis for Genesis and Ford, which will enter the WEC over the next two years. So, guess where at least one of these two manufacturers are setting up their bases, including their race teams? Genesis will continue to produce its engines in Germany, but car assembly and development will take place at Signes.

Pitching up

A quick drive around the complex reveals other companies have pitched up there too, including Multimatic and the IDEC Sport LMP2 team. Unlike many new racecar facilities, IDEC's unit features half-moon windows and elegant brickwork. Inside, one of the few drivers to have taken on Juan Pablo Montoya, and beaten him, sits behind a nondescript desk. Nicolas Minassian was one of the finest behind the wheel in British Formula 3 in the 1990s, and in sportscar racing with Creation, Peugeot and Dome. The grounds surrounding his LMP2 workshop is space that will be taken by Genesis.

Genesis technical director, François-Xavier (FX) Demaison and motorsport boss, Cyril Abiteboul, are both based locally, as is Minassian. Similarly, Hugues de Chaunac, the owner and founder of ORECA. The SRO has its own workshop and car store at the circuit, and Olivier Lyonnet, who was an important member of Stéphane Ratel's team in the '90s, has bought a house at the base of the mountain.

Visiting the SRO workshop as part of a recent family holiday, we saw Jean Rondeau's M379B-Ford sat in a corner. It was being prepared for the Le Mans museum, where it will find a new permanent home. The idea of doing 300km/h down the Mulsanne Straight in this machine is terrifying, yet there's also something starkly beautiful about the ageing racecar's pure functionality.

Meanwhile, in the sky above this burgeoning motorsport cluster, a wannabe stunt pilot was learning how to barrel roll his aeroplane, while Kamui Kobayashi sampled the Haas F1 car around the short circuit below.

Paul Ricard is rapidly becoming one of the most powerful and interesting development areas of international motorsport, and I am looking forward to seeing who else turns up there in the coming years.

ANDREW COTTON Editor

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